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Handbook of sustainable textile production

Marion I. Tobler-Rohr

The Textile Institute

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Handbook of sustainable textile production

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Marion I. Tobler-Rohr



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Foreword

A quantitative assessment of sustainability in the textile manufacturing chain is highly important. Textile products ranging from the fiber to the garment are made, traded, sold, used, and finally discarded worldwide. The technologies, processes, and procedures in use on this life cycle are defined by a few dominating players in business, politics, and technology. Globalized markets have brought a profound change in textile production and sales just recently, and this shift among and concentration on a few major players goes on.

What is the general picture of this global manufacturing network? In the area of raw materials, fibers and polymers, we have government regulation and a few multinational companies setting the rules and the basis for pricing. The same is again valid for the chemical and biological processes in dyeing and finishing, as also in genetic technology.

Different from this, textile processing technology and machinery are dominated by small and medium-sized enterprises. The development of spinning, weaving, knitting, cutting and sewing machinery takes 5–10 years from idea to product presentation and requires an investment in the order of hundreds of millions of dollars or euros in research and development. The typical manufacturer of textile machinery is a family-owned company, the owners being dedicated to traditional machinery construction, willing to support a crew of engineers eager to excel in making machines with ever-growing performance.

It takes generations to accumulate and build up the technical expertise for developing textile machinery. There are only two clusters remaining in the world where this kind of engineering is a core business: north and south of the Alps in Western Europe, and between Osaka and Nagoya in Japan. These two clusters lead in textile manufacturing technology in the same way as Switzerland leads watchmaking, Italy leads fashion, and Japan consumer electronics.

Moreover, the textile machinery market is extremely competitive on cost and performance. The productivity of textile manufacturing processes has shown an annual growth of 4% during the last 200 years, which means that

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productivity has always grown faster than consumption. Consequently, the textile industry is globally shrinking, also in the last 200 years, in spite of the steadily increasing demand of a growing population.

In medieval times, each person had to dedicate more than a quarter of their daily work to cover their personal demand for textiles. Today, the average consumer in an industrialized nation works around 5 minutes per day to cover the cost of the textiles required. In due course, the connection between customer and product has completely changed. The value assigned to a textile product is no longer given by the effort required to make it, but comes from a projection of personal desires and imagination into this product. The symbolic impact of textile goods is perceived to be far more important than the real value in use. There is no longer any connection between manufacturing cost and retail market pricing. How and by whom the items he or she buys have been manufactured is no longer of any concern.

To sum up: the textile manufacturing chain starts on a raw material basis controlled by agricultural subsidies and trade agreements, goes on through a chain of quick-reacting, market-driven processes, and ends up at a customer and consumer who is manipulated by the branding of wholesalers and the discounts offered by retailers. This path is significant not only for the economic behavior of the textile markets, but also for the ecological aspect of textile production and consumption. What does this mean for future innovation?

In a mature technology, innovation is directed mainly to reliability and efficiency of the processes. Both of these targets are identical, regarding the performance in economy as well as ecology. The aspect of resources and environmental impact, further treated here with the term sustainability, is increasingly recognized by the customers. However, textiles are purchased with a time horizon measured in weeks and months. But innovative concepts for processing machinery will enter their useful state only in 5 to 10 years, and – if successful – remain in productive use thereafter for a couple of decades. It is essential therefore that the engineers involved in this innovation have a wide and long-range view of the impact of technology on the environment. They need reliable data and well-founded models of the behavior of nature, in order to direct technology with carefully balanced compromises for providing high-performance products with minimal consumption of resources. Where to get these data?

The partners to provide data on sustainability are scientists in specific areas, such as biology, environmental sciences, toxicology, social sciences, and many more. On this scientific level, data and statistics abound. Different, however, is the situation in the integral assessment of sustainability, which affords compromises between different scales, ratings, and targets. In this area, science tends to promote momentary trends that change with the seasons of the year. This is the weak point for any consideration of sustainability when working on long-range technical developments. While setting targets

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for technical development, there is simply no room for wishful, esoteric ideas.

To fill the gap between the day-to-day changing preferences of sustainability as a public issue, and the long-term commitment in developing technology for the welfare of mankind, Dr Marion Tobler-Rohr was integrated as a specialist in environmental sciences to our Institute for Manufacturing Automation. She invested years into getting acquainted with the terms and the culture of the textile industry, and established communication with the industry, from top to shop floor in production plants. Over a period of 10 years, with the support of students and graduates in environmental sciences and engineering, she collected, checked and researched data on textile manufacturing processes and products. This long-term assignment was made possible by a grant of the Hartmann–Müller foundation for Textile Research. The result is this compendium, which puts its focus on the most important fibers and processes. Given by the availability of scientific data, these come primarily from Europe and the United States.

This handbook is a compilation of technical, economic, and environmental data. It describes the aspect of ecology in a complex, interlaced network of value-adding processes and businesses. There is no intention to introduce a change of opinion or behavior of the public, and there is no promotion of specific solutions, as found in many publications on textiles and sustainability. It is a message on the state of science and technology, intended to contribute to the further development of sustainable products and machinery, within this fascinating area of technology.

Professor Dr Urs Meyer

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Preface

What can be expected from a book dealing with sustainable textile production? Who will read such a manual and what are the aims of the book? To answer these questions the author will reveal her intentions in writing this book, which took about three years, and the development from the first idea up to the present work.

The motivation to write a book was initially related to the habilitation project Prof. U. Meyer offered me in the late 1990s. The idea of producing something physical, even useful to mankind, was very appealing to me.

Ever since working in the area of sustainable development in combination with textile technology, I found myself arguing slightly differently according to the person I was talking to. My partners were farmers, marketing managers, environmental scientists, the LCA community, textile engineers, people from authorities, and consumers in many parts of the world. So when the subject of the manual was outlined, the question was: who will be the readers of this book? I recognized that people working in textile companies were not familiar with working conditions in agriculture. Those who take sustainable development as a philosophy were helpless in finding solid practices in industrial processes. Scientists focused on methods, data and a functional unit, and underestimated the basic knowledge in the textile sector considerably. Cotton growers were not much interested in understanding what difficulties spinning companies had to deal with, as long as they were paid a reasonable price for their cotton. Companies complained about unfair competition through national environmental legislation. Consumers believed only natural fibers are good fibers, and economists wanted to have single figures or rules instead of time-consuming LCA results which nobody understood. Engineers feared for losses in innovation if they found themselves restricted to sustainable development. Finishers were sick of being accused of polluting the whole world and wanted consumers to be educated. Marketing managers believed sustainable development was not of any concern to them, and particularly not their responsibility. Our societies have moved towards convenience living in many parts of the world. Youngsters no longer know what material they are wearing, and so on. The misapprehensions could be continued. The list

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is by no means meant to blame the people involved: my own pathway in researching this field is paved with many of these prejudices. I was lucky to meet many people who were willing to make me acquainted of the real nature of things, even if I sometimes had to make up my mind between different viewpoints.

Talking about sustainable development, I was confronted with more different beliefs than there are definitions in the literature. Again and again I learnt how important communication in this field is. Even if I never intended to deal scientifically with the term, I had to define it for common understanding and to take a position.

The question I had to go over and over again was: how can I transfer my knowledge to almost all the people who might be interested in textiles and apparel in relation to sustainable development? Knowing that on the one hand I have to fulfill superior academic requirements, and on the other to make the results understandable to the majority of the non-academic people involved, I was searching for groups of interests and groups of issues. I found the answer after several trials in the structure presented here.

Chapter 1 is dedicated to sustainable development, a philosophy developed as a scientific issue but also as a belief of people and organizations to be applied in practice. Here the reader is given a brief overview on the multiple definitions and understanding of the term. It shows how theoretical concepts are translated and simplified into applications for authorities and the private sector. Some commonly used instruments are introduced on how to identify, measure, quantify, and communicate environmental aspects in our every day life and in science. Specific attention in this area is drawn to the textile sector.

When writing I had both environmentally oriented managers and consumers in mind, but also the academic requirements for the background of the studies. Producers and consumers are given information about environmental management systems and labeling systems, including environmental product declaration and eco design.

Basic information in the form of a survey on the textile chain is presented in Chapter 2. It starts with fiber production with its variety of raw material, followed by textile processing and technologies in yarn and fabric production. The greatest variation is found in finishing processing and technology, where many aspects of fashion, comfort and special properties are adapted. The manufacturing of apparel is directly oriented towards consumption, a process everybody is personally involved in. Interested consumers, authorities and also beginners in textile technology will find simple descriptions of production stages and thereby get access to the complexity of the ‘textile world’. They will get an insight into processing and an understanding of interactions along the value-added chain. Environmentally oriented readers may find themselves confronted with options and limitations in process technology.

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Especially the part dealing with consumption and disposal is intended to sensitize readers to changing their own behavior. For science this chapter represents the description of the system investigated. This overview does not claim to be complete, but to allow simple comparison, for example by means of indicators. For sustainable development in practice, indicators are sufficient to develop strategies for management or personal choices.

The survey represents a summary of my lecture for environmental scientists and engineers at ETH based on my own research and on the seminars and workshops I organized in the area of textile technology and ecology, as well as on information from companies and from the literature. Some aspects are highlighted and are dealt with in more detail, because they represent basics or practical experience gained in studies (see research program), the results of which will be presented in later chapters of this book. These case studies will allow the reader not only to read the book from beginning to end, but also to switch from chapter to chapter to find all information about a specific case study.

Chapter 3 is based on the previous chapter and indicates ways to specify quality and functions of textile products on the individual process steps. Based on approved quality parameters in agriculture, business and trade that are again highlighted and detailed in selected aspects, a simplified system for textile specification is elaborated. The purpose of this highly structured system is to optimize textile processing based on measured, quantified parameters of quality and through improved communication between business partners along the value-added chain. If textile specifications are applied in electronic data exchange, they represent a competition factor for the users, in superior process control and in faster product development. Part of the textile specification is also suited to providing detailed information for consumers to make appropriate choices. Hence this section may interest both producers and advanced consumers.

The aim of Chapter 3 is also to define functionality of products. Regarding the countless variations in apparel it is essential to adapt the functions of apparel to the desired use. To achieve an optimized match of processing and functionality is a major contribution to reducing textile waste and thereby adding to sustainable development. This part of the chapter provides information on how desired properties of a product can be achieved in specific processing and shows interactions among properties. Such knowledge is important for product development, which too often is driven by fashion only. It may become important also for readers who are especially interested in marketing (see Chapter 5).

The third part of Chapter 3 provides requirements for ‘best available technology’ (BAT), an activity of the EU for improved environmental protection. A BREF document has been published as mandate of the ‘Integrated Prevention and Pollution Control’ (IPPC) with the European

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Union, focusing mainly on finishing processes. BAT is completed in this part with recommendations for all processes in the value-added chain of textiles and apparel.

Basic environmental research such as life cycle assessment (LCA) of (almost) all succeeding processes is presented in Chapter 4 with some variations. This represents the first and only assembly of process LCA, based on individual measurements and including all steps from cotton growing, spinning, weaving and finishing to consumption. The studies were carried out between 1996 and 2005 and the same software was used throughout for the calculations. The environmentally interested reader may be fascinated by such accurate results. Nevertheless, as different methods have been applied, comparison is complex and requires a careful evaluation of the uncertainty, which is added to the results in a classical scientific form. As the results are closely related to scale, scope and functionality, they are also interpreted with this background. There is no need to emphasize that this section is especially dedicated to science, even if the results are interesting to all readers, whom I encourage to read carefully.

When drafting ideas for this manual, I noted the need to develop a simplified method for application. This was set without having determined a vision of its nature. But from the beginning it was clear that full LCA was not the solution. Indicators seemed too vague and inventories were often confidential. Marketing strategies showed that existing methods had failed. My work as chairwoman of the COST action working group on LCA in textiles provided an insight into European research activities and company practices of 19 nations. So I took courage and developed the idea of ecological key figures. They are based on equations for individual processes along the value-added chain, taking into account main specific circumstances in production as well as basic environmental impact assessment. I believe future-oriented companies will prefer this instrument for quick calculation of environmental impacts. The scientific evaluation will state that it is a simplified method, not as accurate as LCA but based on available data from the textile industry.

In Chapter 5 a completely different viewpoint is introduced: the marketing perspective. As marketing is overwhelming in its economic importance, the consequences for sustainable development are indirectly influenced by its decisions. The push strategy coming from the value-added chain has almost disappeared in favor of a pull strategy from product development and marketing, establishing new rules by working in a global environment. During many visits and a sabbatical in the USA I had the opportunity to add the American perspectives of the large merchants to those of Swiss and European small and medium-sized companies. Also, markets and consumer behavior are compared in this chapter, allowing one to draw some predictions from one market to the other. This chapter is important for consumers and product

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development. It must be considered also for scale and scope definitions of scientific studies, if they should be based on reality.

Literature is cited at the end of every chapter. There are also some links to actual versions of documents cited in this book.

Marion I. Tobler-Rohr

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Acknowledgments

First of all I want to thank Professor Dr Urs Meyer who offered me the opportunity to enter a new research area, to learn about textile processing and machinery and business processes. In his very special style Urs Meyer led his staff, including me, towards a high level of responsibility in textile research. The cooperation with textile engineers opened new horizons to me. By nominating me a member of the research commission of the Swiss Association for Textiles (TVS) and editor of the Klippeneck seminar proceedings, he allowed me to establish an environment with excellent partners in industry for discussions about quality and functionality.

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In all the years of research I met many experts in textile technology at many seminars and congresses, who increased my knowledge with their valuable contributions. Among them I wish to give my special thanks to Dr Ulrich Meyer, who guided me gently through the finishing processes. Professor Petra Blankenhorn involved me in her interesting studies at Fachhochschule Albstadt Ebingen.

Invitations to Eastern European textile congresses, combined with industry visits, imparted me knowledge about this important textile area and its attempts towards sustainable development (SD). I felt honored to be invited as first European expert on LCA to Thailand's textile industry and authorities. The kind reception I received and the decisive direction taken towards SD impressed me deeply.

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Since 2001 I have met many textile researchers from all over Europe during COST action 628 who allowed me to learn about the research in the 19 countries involved. First of all I wish to thank the chairwoman Professor Eija Nieminen from the Technical University in Tampere who started the action and enabled the European networking. She trusted me as much as to lay the guidance of working group 1 in my hands. Special thanks go to Dr Maria Walenius Henriksson who not only was an excellent co-chair but also became a friend. I experienced great cooperation from many colleagues when coaching Task Force BAT within the COST action. I cannot name all my colleagues in the COST action who were willing to share their research but I greatly appreciate all their cooperation.

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1
Sustainable development (SD) as a goal in production, marketing and trade

Abstract: A brief overview on the multiple definitions and understanding of the term *sustainable development* is given: as a philosophy, as a scientific decision-making tool, but also as a belief of persons and policy to be applied in practice. It shows how theoretical concepts are translated and simplified into applications for authorities and the private sector. Some commonly used instruments like environmental management systems and labeling systems, environmental product declaration and eco design are introduced on how to identify, measure, quantify, and communicate environmental aspects in our everyday life and in science. Specific attention in this area is drawn to the textile sector.

Key words: sustainable development, environmental policy, environmental indicators, environmental management systems, eco labeling.

This chapter is for managers developing SD marketing strategies, for politicians developing SD policy, and for authorities setting the framework for SD in the textile sector.

1.1 A holistic concept

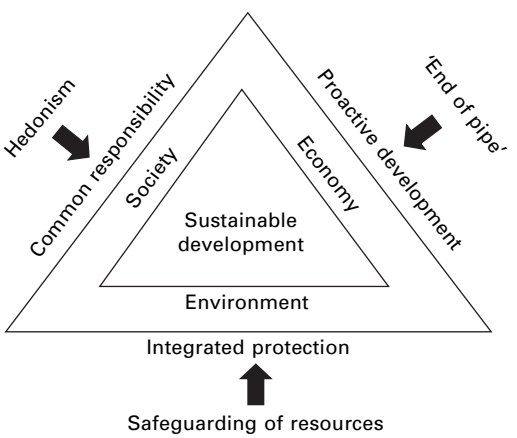
Is 'sustainable development' an overstressed expression? It has become very trendy to use the term sustainability for underlining any turnaround leading to a 'golden age'. Also it is generally agreed that 'sustainable development' (SD) characterizes a process towards a goal which cannot be defined very precisely. 'Sustainable' is often used synonymously with having a 'serious intention' or being 'long lasting'. There is no way to prevent people from applying words and terms in their own language, whereby the meaning can be completely changed. Similar ambiguities can be found in the terms 'environment' (in economy or ecology) and 'product life cycle' (again in economy or ecology). Consequently the question arises whether the term 'sustainable development' should be replaced by another expression. This must be denied for three reasons: first, it will not be easy to find an acceptable term; second, a new term could be applied in a misleading way; and third, a long-lasting process like sustainable development should not be renamed while it is in action. But now: what is 'sustainable development' all about?

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1.1.1 Sustainable development and its goals

The definition in the Brundtland report of the World Commission on Environment and Development, '… development that meets the needs of the present without compromising the ability of future generations to meet their own needs', is still considered as one of the most accepted (Brundtland 1989), even if the expression is not very detailed, or perhaps exactly because it is so vague. Sustainable development describes in the most simple way a long-term strategy including economic, human (social) and environmental (material) resources. This means a threefold strategy: to run a business based on the return rates of a capital stock but never on the capital itself, to respect and apply the framework of human rights in society, and to use environmental resources within the Earth's carrying capacity.

Today more than 200 definitions for SD can be found. Generally they all refer to the three pillars: economy, society and (ecological) environment, whereby the equivalent value of the pillars should be a goal, which certainly is difficult to achieve in practice. The starting point is the awareness of an ethical responsibility (see Fig. 1.1, Tobler 1996). Values and ways of cooperation within the disciplines have to be changed towards a new paradigm. Eventually the safeguarding of individual resources, like water or forests, will lead to holistic environmental protection, and people will abstain from hedonistic self-realization in favor of a consensus-oriented common responsibility. For industry and economy, this means a shift from 'end of pipe' solutions to proactive development and integration of external costs of environmental impacts. Concepts in cooperation of the three pillars will lead



1.1 The three pillars for sustainable development: the trend towards this goal will succeed only if (a) society becomes aware of a common responsibility, (b) environmental protection becomes an integrated search for solutions, and (c) industry prevents pollution by means of proactive actions.

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to implementation in many areas, like policy, legislation, technology and education. The key actors in a framework of sustainable development can be found in policy, industry, economy and education. For our framework of implementation, we operate with the following working definitions (WWF/IUCN/UNEP 1991):

- Sustainable development keeps natural resources within the ecological capacity of the Earth and preserves its vitality and diversity. Non-renewable resources and renewable resources are used only to the extent that they can be replaced by renewable resources.
- Sustainable development enhances worldwide human quality of life, equalizes the North–South gradient in wealth, and develops new technologies as well as environmentally compatible forms of trade.
- Sustainable development creates a global alliance and enables communities to care for their local environment. It changes personal values, attitudes and behavior to implement the goals of sustainability.

Origin of the term sustainable development

It would be shortsighted to believe that environmental problems were a child of the twentieth century. Mankind has overstressed the environment in earlier years: to mention only the deforestation of the Mediterranean area which resulted in karst formation, or London's air pollution in the seventeenth century caused by heating with coal of a high sulfur content (Sieferle 1988). Some of these impacts are irreversible and others have been solved only by drastic reductions in population as in wars or pandemics. In the 1950s some examples of environmental pollution on a larger scale became evident (e.g. the nitrification of lakes in Europe) and energy resources became limited (leading to the oil crisis of the 1960s). Many publications brought up the issues of ecological impact assessment, limited resources and environmental damage caused by mankind. Early scientific statements were made by biologists (e.g. Carson 1962, 2002). NGOs such as the Club of Rome (Meadows *et al*. 1972) clamoured for more environmental protection in the 1970s as a consequence of the energy crisis. National environmental legislation and international treaties were the answer to these ecological problems in the last decades. However, industry fought against fundamental green ideas, aiming towards maximization in earlier years.

Sustainable development was originally conceived by forestry in the nineteenth century to provide timber for the next generation (Henning 1988). When Brundtland used the term again in her report (Brundtland 1989), she gave it a new direction for environmental concerns in the industrial world. By creating this new term she avoided the time-worn expression 'ecology'. The paradigm change allowed industry to identify with the new goal in a proactive way, based on optimization of economic, ecological and social

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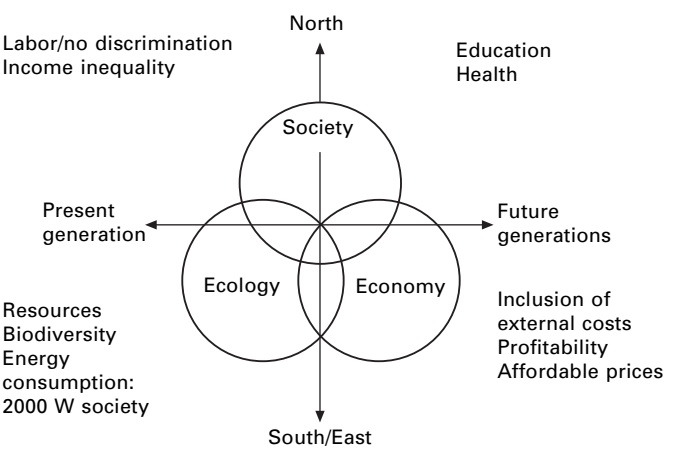
aspects. Today's understanding of sustainable development must include a balance of ecological, economic and social aspects to act in a treaty between wealthy and poor societies and towards coming generations (see Fig. 1.2).

Focus point: the Earth Summit in Rio, 1992

In the preliminary stages of the Earth Summit in Rio different groups in policy, science, industry and NGOs prepared concepts for sustainable development. The interdisciplinary or holistic approach was new to everybody and required new methods of cooperation and consensus finding, which was not easy. The most prominent *Strategy for Sustainable Living* (WWF/IUCN/UNEP 1991) emphasized strongly the ecological and social aspect of sustainability, since environment is the most neglected part, as follows:

- Respect and care for community and life
- Improve the quality of human life
- Conserve the Earth's vitality and diversity
- Minimize the depletion of non-renewable resources
- Keep within the Earth's carrying capacity
- Change personal attitudes and practices
- Enable communities to care for their own environments
- Provide a national framework for integrating development and conservation
- Create a global alliance.

Finally 181 nations negotiated the Agenda 21 at the summit in Rio, an environmental action program for the twenty-first century to care for sustainable development of our planet.



1.2 The three dimensions of sustainability.

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The framework program was continued under the UNO leading among other activities to a second world summit in Johannesburg,[1] which took place in 2002. Despite some individual success stories, the review of 10 years of coordinated activities caused deep disillusionment concerning the goals achieved. Many other organizations, non-governmental and governmental, have established useful guidelines for sustainable development (see Section 1.4.3). However, implementation has been achieved only by a few nations.

1.1.2 Motivation for sustainability

Why do some people or organizations behave or act in a sustainable manner and many others do not? Some personal thoughts will be shared here. It has always been recognized that people followed ideals of prominent persons and identified with them. Before the age of 'total information' by Internet such ideals were taken as impeccable. So maybe we are missing today these 'icons' for environmental protection, even if some prominent persons are active, such as Mikhail Gorbachev, who even founded a new organization (Green Cross) for environmental protection, or former US vice-president Al Gore, who works on convincing people of the need for environmental protection (Gore 2000, 2006). People may not wish to identify with ascetic environmentalists, preferring a certain level of comfort and well-being. On the other hand, we have many examples of decreasing quality of life due to environmental pollution, particularly air pollution and dramatic climate change. Areas where people personally behave in an environmentally friendly way vary a lot and are often coupled with economic considerations. A very prominent example is personal mobility: although Europe has developed a very good system of public transport, the value of personal freedom, to move whenever and wherever the individual wants, is very high. Consequently, transportation by car is still very popular, though in a full cost allocation it is not always the most economic decision and often not the most time saving. In the USA transportation by car is essential because no comparable system of public ground transportation has been developed, covering the whole country.

In personal behavior it is still possible to distinguish between sound environmental responsibility, practicable actions with a 'sustainable product', and even unintended (or unknown) sustainable behavior (Hirsch 1993). Even an oral commitment to sustainable development does not necessarily imply a consequent action towards that goal. This becomes particularly important for industry leaders, who will be judged according to their credibility. Decision makers in industry are responsible whether a turn towards sustainable

[1] www.johannesburgsummit.org

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development takes place or not. They are often guided by a short-term risk perception. Insurance companies have provided figures on how risks have changed and on the costs of more frequent environmental risk events (see Section 1.2.3). The future will show how fast environmental impacts will change our personal lives and our economies – and whether we will be able to stop and reverse this development.

Europeans are trained to claim that they do care for the environment, which to a certain extent may be true. Americans are sometimes more honest in making clear statements against environmental protection (for economic reasons). There is a strong political force for green thinking in many European countries, while in the USA such movements are focused by NGOs.

Individual well-being and wealth and recognized human rights are by no means in balance. Much discrimination nowadays occurs due to differences in religion but also because of inequity in access to education. To give an idea about the world's representation, we consider it as a village of 100 people as follows:

- 57 Asians
- 8 Europeans
- 13 Americans (North and South)
- 22 Africans

or

- 52 women and 48 men
- 30 white and 70 non-white
- 30 Christians and 70 non-Christians
- 89 heterosexuals and 11 homosexuals

or

- 6 persons own 59% of all wealth (all US citizens) all living in the USA
- 80 persons are living in buildings
- 70 persons are analphabets
- 50 persons are undernourished
- 1 person is dying
- 1 baby is being born
- 5 persons own a computer (US citizen)
- 1 person has university education.

1.2 Theory behind sustainable development

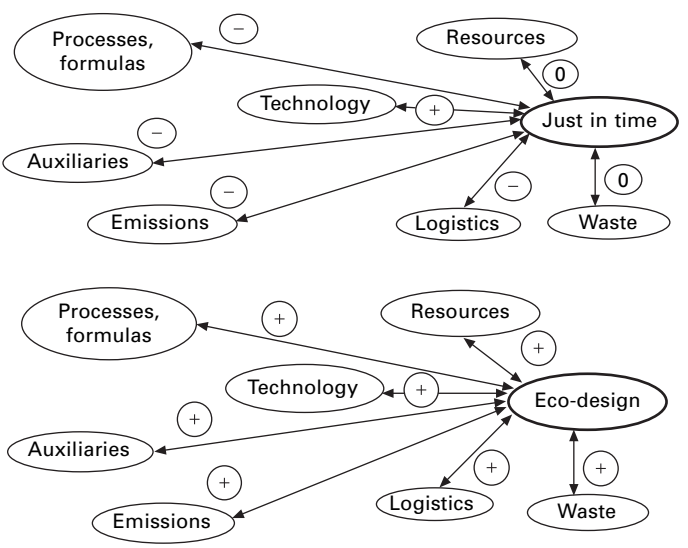
Among the three pillars of sustainable development different restrictions have to be made, if the three of them are to be optimized. Each of them can easily be defined by its inherent disciplinary theory. However, in practice the

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three disciplines are strongly influenced by each other and changes in one discipline occur not independently of the others. What has to be achieved is an interdisciplinary approach, based on the disciplinary theories and adapted to practice. Economics provides the largest variety of theories being verified or falsified under ever-changing practical circumstances. Social theories are always context-related over time and place according to society's values. Environmental theories for impact assessment are only at a starting point, developed from basic research on phenomena which science is just beginning to understand.

1.2.1 Economics and trade theory

Economic strategies have been developed in both theory and practice and have been applied and adapted in an ever-changing micro- and macro-environment. Economic growth is the most dominant controversial argument against sustainable development, although economists (Block 1990, Binswanger 1991) have shown ways for qualitative growth instead of pure quantitative growth. The former can be achieved by adding value and increased lifetime to products. Today management trends in many companies go towards short-term economic benefits. Flexibility is required as opportunities may arise very quickly due to changes in the macro- and micro-environment of a company. The micro-environment of a company and goals of sustainability are strongly interdependent (Fig. 1.3).



1.3 'Just in time' strategy versus 'industrial eco-design': + = positive impact, – = negative impact, 0 = neutral.

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In the textile and apparel sector, life cycles have always been seasonal and become even shorter (see Chapter 5). These activities are strongly supported by shareholder values and the policy of many financial institutions. But if long-term strategies are lacking, such companies run a high risk of going out of business (Töpfer 1991, Dyllick and Schneidewind 1995). Leadership and operation including the long-term marketing strategy of sustainable development can be considered a solid base for companies even under hard competition (Ernst Basler + Partner AG 1993). A 'trendy commitment' towards sustainability in industry and commerce will not be enough to yield business benefits. So-called 'green funds' show better performance even in hard times than the average of all funds (Schaltegger and Figge 1998). Such facts provide evidence for the economic benefits of sustainable conduct in business.

A theory of global marketing and trade was well defined long ago (Porter 1986) by indicating key factors for political and national economies (see Fig. 1.4). Nations must strengthen their competitive advantage and factor conditions like labor supply, technology and infrastructure in order to participate in global trade. Industry can benefit from close partnership and relationships with customers and employees as well as competitiveness in domestic markets. In the agricultural sector, where crops and fiber materials are grown, production is strongly influenced by national macro-economic factors such as segmentation of rural and urban populations, GNP, subsidies,

Absolute advantage of a country: Manufacture of a good by using smaller quantities of resources	Silk: Japan; cotton: China
Comparative advantage: Manufacture of a particular good more efficiently than the other country	Relative differences in productivity of labor
Factor conditions:	– labor supply – infrastructure
Demand conditions:	– domestic market shapes innovation – continual upgrade of companies by clients
Related and supporting industry:	– rapid access to cost-effective inputs – partnerships with related industries (technology)
Company strategy, structure and rivalry:	– leadership (motivation of employees) – attitude towards international activities – relationship with customers – competition in domestic markets
Qualitative growth:	– increase services – dematerialize products

1.4 Economic factors for sustainable development based on trade and growth theory but including qualitative growth instead of unlimited quantitative growth.

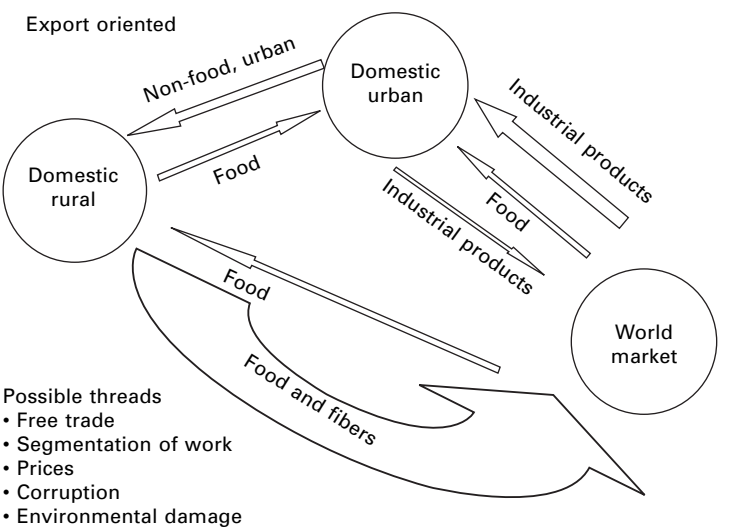
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import and export of agricultural resources, and quotas and tariffs under the WTO.

For developing countries competitiveness in domestic markets is an important condition, especially to avoid dependency on industrialized countries. Exports based on a small number of food and fiber products may only be a pioneer situation (Fig. 1.5) and should be developed towards strong domestic markets for domestically produced food and goods (Fig. 1.6). In many ways economic benefits are directly related to the social aspects of human welfare.

1.2.2 Human rights and social theory

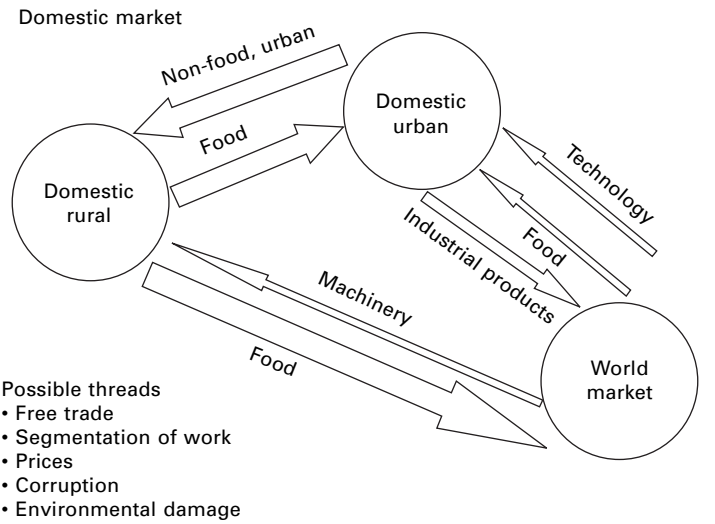
Social aspects may be considered differently in different parts of the world. In industrialized countries, where working conditions are negotiated by contracts and supervised by unions, the trend is towards social ethics, which are discussed in a global perspective. The agreements on human rights of the Geneva Convention[2] are mainly met in these nations. Today national legislations of developed countries set criteria and limits for the working environment in order to increase working safety, ergonomics and occupational health. But working conditions in developing countries often do not even meet the following agreements on human rights, nor the 'three freedoms' (UN 1945):



1.5 Development driven by export of agricultural goods.

[2] http://www.hrweb.org/leagl/undocs.html

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1.6 Development based on domestic markets.

- The right for legal recourse, when their rights have been violated, even if the violator was in an official capacity
- The right to life
- The right to liberty and freedom of movement
- The right to equality before the law
- The right to presumption of innocence until proven guilty
- The right to appeal a conviction
- The right to be recognized as a person before the law
- The right to privacy and protection of privacy by law
- Freedom of thought, conscience and religion
- Freedom of opinion and expression
- Freedom of assembly and association.

The International Labor Organization (ILO)[3] reports continuously on working conditions of individual sectors (Torres 2001). Social aspects are monitored and indicate specifically that discrimination by race, religion and gender is the main problem nowadays. The sector of textiles and apparel is well documented as this represents a pioneer industry for many developing countries, and patterns for global changes in industry can be deduced.

The industrialized world developed its own social values for human work, starting with a strong segmentation of work ('Fordism'). In changing from craftsmen to workers, responsibility for products was shifted away from the individual working person into a strongly hierarchical structured control

[3] http://www.ilo.org

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system. In these early years of industrialization the social values were set by Protestant ethics (Kern and Schumann 1984) demanding punctual appearance, cleanness and precision of labor. Over long periods workers could count on lifetime employment by fulfilling these requests. Today as the industrialized world suffers from unemployment among blue-collar workers, new values like flexible specialization are required (Piore and Säbel 1989). However, new models for the definition of work also include social and environmental work. Such values may contribute to a new social contract among employees and entrepreneurs within a sustainable society (Von Rosenstiel 1991). OEBU/TSF/zsa-ZHW (2005) show that socially sustainable entrepreneurship contributes to economic success.

Hence, companies should invest in motivated and skilled personnel. A company that overstresses personnel through low salaries and rigid working conditions may not expect to be innovative. It may operate on an economically maximized level for a limited time. As soon as the environment changes it risks going out of business as people will not be able and willing to adapt accordingly. Human resources are considered to be the capital of a successful business and require activities like the evaluation of employer satisfaction (EFQM[4]).

1.2.3 Environmental theory and impact assessment methods

Environment in the ecological sense can be described as the biosphere, created and ruled by nature, as opposed to the anthroposphere, which has been created and ruled by people. Conflict lies within this definition in setting thresholds between human activities and their impact on ecosystems. As the balance of ecosystems is a very fragile interaction of all species involved, research simply cannot predict the behavior of ecosystems under the changing influence of anthropospheric impacts. Climate change has not only increased linearly but accelerated in the last 20 years.[5] Only in recent times has it become possible to include the enormous amount of influencing factors in a computer simulation model of the ocean rolls. But the uncertainties are still large insofar that we do not know exactly to what extent temperatures will increase or decrease. Such uncertainties make it difficult (especially for politicians) to implement the right measures. On the other hand, we have clear indications from IPCC of how fast we have to react in order to prevent drastic climate changes.[6]

[4] European Foundation for Quality Management, www.efqm.org
[5] http://ec.europa.eu/environment/climate/home_en.htm
[6] International Panel on Climate Change, report 2007

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A life in balance with the environment is most difficult to achieve for the individual. Due to the segmentation in our working environment, we are no longer used to fully recognizing the consequences of our activities. Dealing with a sustainable environment means following an approach 'from cradle to grave', a life-cycle perspective of goods. Because many goods are processed only at selected stages of their life cycle, companies focus more on optimization of a facility than on goods or services. In individual and practical life, monitoring by means of indicators is easier to carry out and to understand. For industrial purposes, calculation by means of life cycle assessment can be an appropriate measure. A careful adaptation of our anthropospheric activities to the carrying capacity of our planet is probably the most demanding task for the twenty-first century.

Research and applied research try to provide us with environmental information for decision taking. There are two main areas in research to develop a theory for environmental damage assessment: first, indicators have been developed to estimate impacts (see below) on an inventory base; and second, scientific impact assessment tools like life cycle assessment (LCA) and ecological key figures (EKF, see Chapter 4) assess the impact of the inventories and thereby give a holistic assessment of the damage.

Indicators

Environmental indicators for the public sector and the industrial sector vary considerably due to their inherent goals, although in both areas they have to give information about the nature of the measured value. Popular ideas based on 'material intensity per service unit' have been created (Schmidt-Bleek 1993) and developed further (Stahel 2000). Continuous monitoring of the nature of development helps to find the indicators for non-sustainable development. Economic calculation of the measures required to protect the planet from anthropospheric environmental damage is given by risk assessment. As the frequency of environmental damage has increased significantly, calculation of risk can no longer be described according to:

$$r = f \times wca$$

but on: $r = wca$ (where r = risk, f = frequency, wca = worst case accident).

Such risks and damages are of global concern, and some of them have been negotiated in global political actions like the Montreal Protocol (UNIDO, www.unido.org/doc18256) regulating the emission of fluorinated and chlorinated hydrocarbons (FCHC).[7] The 'Basel Convention' prohibits trade with waste, particularly with developing countries. This convention has

[7] FCKW in German

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been negotiated by the EU and many other countries but not by the USA. The 'Kyoto Protocol' (UNIDO, www.unido.org/doc/13941) obligating nations to take action against further global warming is in the process of negotiation. Again, the USA hesitates to sign.

Environmental indicators require a quantified analysis of material flows, growth rates, functions of growth and setting of limits. An important factor is the difference between material flows and stocks, since large stocks may suddenly be turned into flows of different dimensions (Baccini 1996). Growth has to be evaluated in relation to the capacity of the environment to adapt without damage or losses, if meant to be sustainable. A first step to identify limits is to find and fill missing control loops (Meadows 1995). Critical developments follow qualitatively as:

$$\frac{dc}{dr}$$

where c = change of impacts and d = reaction of the environment. This ratio is necessarily modeled in a time graph.

While the public sector has to include all human activities (the anthroposphere), industry focuses on production and the value-added chain of its products. Consequently, indicators and fields for actions and improvements in the public sector are multiple, compared to the product- and service-related action fields in industry (see Section 1.4). Moreover, the public sector represents specific national circumstances (see Section 1.3). There is a strong relation between the two areas for implementation, as the public sector defines the framework for industry. Organizations deal with specific industrial sectors and connect their needs to international public requirements (see Section 1.4.3).

The easiest way to make estimates is to work with indicators. However, such estimations provide values based on different units, which make comparison very difficult, if not impossible.

Scientific impact assessment tools

Only in recent times have scientists started to develop models and methodology for global impact assessment resulting in methods of calculating life cycle assessment (LCA) (see Chapter 4). These modeling aspects and methods are still in an early stage of development and can provide only limited scientific accuracy for actual impacts, due to the complexity of interaction in our biosphere. But they are the best we have for scientific assessment. In many practical applications LCA is even too detailed. This book proposes also a simplified method, based on LCA experience: ecological key figures (EKF), including damage assessment.

The only way improvements towards sustainability can be measured

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is by means of quantified dimensions. The scientific tool for comparison is life cycle assessment, based on individual processes carried out. Such investigation requires more detailed information than is generally available, even in companies with integrated management systems. Studies covering the value-added chain of textiles can be carried out only by independent institutes, whereby inventories are collected from all companies in the value-added chain. For companies with highly developed data collection methods at a process level, LCA can be an appropriate tool. In Chapter 4 the methodology for LCA is deduced and LCA research results for different processes and products along the value-added chain are presented, compared and evaluated according to ISO.

A simpler way is to develop key figures, which are well known in economics but applied less to social and environmental impacts. Preferably, a key figure is related to a production or output unit: per ton, per annual production, per product unit, per employee, etc. Key figures for environmental, social and economic impacts have one characteristic in common: they are highly dependent on the business. Specifically for textiles they are different for each step in the value-added chain: spinning, weaving, finishing, manufacturing, trade and retail, and they even vary for different fibers. Therefore specific ecological key figures (EKF), including damage assessment for the textile sector, have been developed and are first presented in this book. The assessment is based on detailed LCA studies.

Both ecological key figures and LCA can be applied to environmental labeling (see Section 1.6). Other methods, such as 'multicriteria analysis' (Scholz *et al*. 2003), also include the actor's behavior and support the process of decision finding. Generally they are applied when many actors (stakeholders and shareholders) are involved.

1.3 Sustainability in the public sector

Considering the demand for urgent action, it becomes evident that policy and public administration of nations should set an example. However, in global (political) activities this becomes difficult, because the democratic process is time consuming and requires participation of all involved parties. To establish a legal base for specific environmental protection and to implement such legislation is a complex task.

For companies it is easier to develop and implement strategies if the management stands behind the commitments (see Section 1.4). An international index, the Environmental Sustainability Index (ESI),[8] rates individual countries according to their ability to deal with environmental questions, including the following five aspects:

[8] www.yale.edu/esi

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1. Maintain a vital environmental system at a healthy level
2. Keep the anthropogenic stress on the environment low enough to prevent harm
3. Reduce human vulnerability to environmental disturbances
4. Consider the capacity of networks and social patterns, fostering effective responses to environmental challenges
5. Foster international cooperation to manage environmental problems (by global stewardship).

1.3.1 Environmental policy and legislation in the USA

In the USA there is no formal strategy towards sustainability as a national commitment and obligation. Sustainable development consists of a number of programs in certain areas. Actual policy promotes sustainability as 'P3': benefiting people, promoting prosperity, protecting the planet.[9] However, the documents about processes are classified, suggesting an apparent antagonism to the requirement of participation. The USA does not participate in the program for sustainable agriculture driven by the OECD, claiming that the domestic economy would suffer under such commitments. Under Democratic administrations, environmental protection generally has a higher value.

Environmental protection in the USA depends strongly on the administration in office. Republican administrations work for smaller restrictions imposed by environmental legislation. Consequently the Environmental Protection Agency (EPA) can run some programs only under Democratic administrations and might have to stop them under Republican administrations. The US State Department's first annual report on the environment and foreign policy represented a new way of looking at the world, when 'Information on Environmental Diplomacy' was published under Vice-President Al Gore.[10] The EPA provided a 'Design for Environment' program specifically for textiles in 2001, including a series of cleaner technology programs. However, there is no control function associated with these programs. The USA has refused to negotiate not only the Rio declaration but also the Kyoto Protocol for climate protection. In July 2005 the USA, together with China, Japan, South Korea and Australia, launched a competing climate pact, which should allow increasing energy consumption under parallel reduction of greenhouse gases. Considering the steady consumption of 10,000 watts per US citizen, compared to the average European consumption of 5000 watts, such attempts

[9] www.epa.gov/sustainability/
[10] www.state.gov/www/global/oes/earth.html

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will never allow the achievement of a balance with a 2000-watt society.[11] Among the EPA's research subjects there are no textile issues.[12]

1.3.2 EU environmental policy and legislation

Soon after the World Summit on the Environment in 1992 the EC developed its first general guidelines towards sustainability (Enquete-Kommission 1994). This action was pushed by many European nations with a strong 'green' political force and 'green' oriented governments. (Only in a multi-party democracy like those of most European nations is such a development feasible; the two-party system of the US prevents such developments.) With the enlargement of the EU (see Fig. 1.7), strategies were elaborated to be applied in specific sectors. Authorities are aware that they have to set examples in their own activities and report them.

Economically the EU will benefit from member nations with lower wages but a skilled workforce. Increased cooperation between established research institutes and industry will drive the technology and innovation factor. The introduction of information technology also in small and medium-sized enterprises (SME) will improve partnerships with existing and new partners in a network. Among the social aspects, non-discrimination by religion and gender will be issues to cope with. The great differences in income will decrease due to competition from Asia. Exchange and free access to research and employment will fertilize the economies and equalize chances for the population. The initiative was taken by the common European Directive 96/61 on 'Integrated Pollution Prevention and Control (IPPC)' in 1996, setting standards for best available techniques (BAT) in order to provide authorities with guidelines for control (European Commission 2002). Implementation of the IPPC should also be associated with additional costs, and integrated product policy (IPP) with a life-cycle perspective of produced goods. Companies are encouraged to implement environmental management systems (EMS) and to establish environmental labels for their products. The goals for sustainable development in the EU 25 are:

- Changes: Partnership with employees and authorities
 Public procurement
- Research: Improve new processing
 Intensify investments and research
 Integrate research (universities–industry)
- Innovation: Close gap between research and application
 Improve information management (B2B)

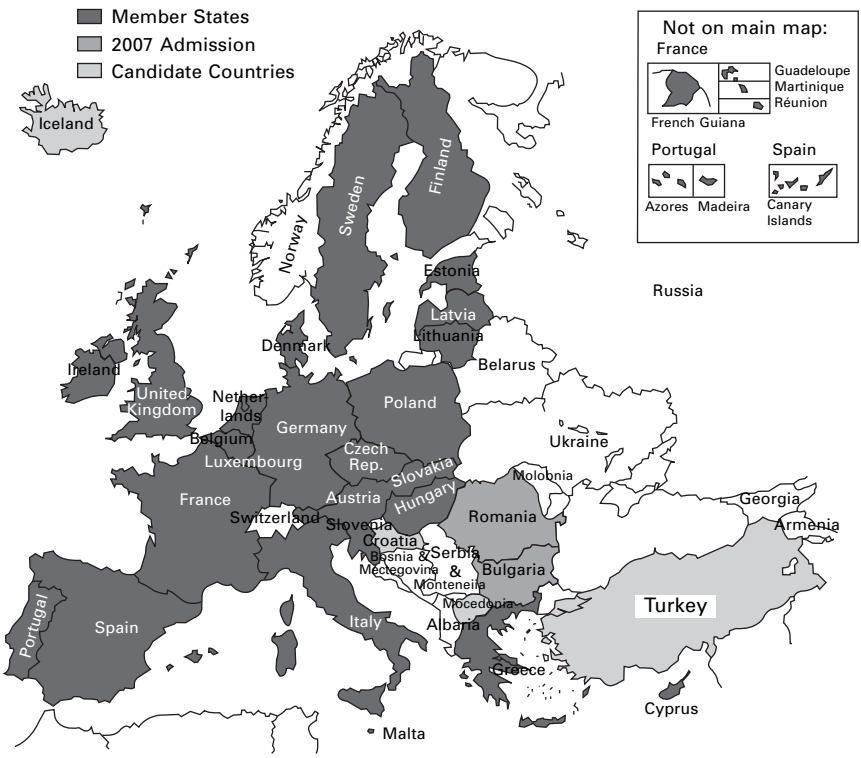
[11] A developing country has a steady consumption of 1000 watts per person: www.worldchanging.com/archives/002829.html

[12] http://es.epa.gov/ncer/rfa/current/2003_valu_environ.html#scope

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- Environment: Reduce amount and load of wastewater
 Introduce life cycle perspective
 Apply IPPC (96/61, 1996)
 Integrated product policy (IPP)
 Encourage environmental management systems and environmental labeling
 REACH: registration of chemicals
- Intellectual property: Harmonization of legislation.

The European Parliament has made a strong commitment to environment protection and has developed strict regulations to be implemented in all



1.7 The European Union with 27 Member States (2007). Year of countries joining the EU: 1952 Belgium, France, West Germany, Italy, Luxembourg, Netherlands; 1973 Denmark (with Greenland), Ireland, United Kingdom; 1981 Greece; 1985 Greenland leaves EU; 1986 Portugal, Spain; 1990 East Germany was reunited with West Germany; 1995 Austria, Finland, Sweden; 2004 Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia; 2007 Romania, Bulgaria. EU 15 = countries 1952–2003, EU 25 = countries 1952–2005.

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member countries. The European Environmental Agency has led the member countries to harmonized legislation with a strong focus on sustainable development.[13] The EU has taken an active role in developing strategies for sustainable development in public and industrial areas.[14] Member countries such as Germany have evaluated their specific indicators for monitoring the process towards sustainable development. Combined efforts of legislation and voluntary actions can be shown in a comparison of the environmental impacts of 1990 and 2000, clearly accounting for reduced or stabilized environmental pollution by industry in Europe (Torres 2001).

Summarizing, EC 20/97 'Towards Sustainability' in the early 1990s set priorities in energy efficiency and production efficiency. It was followed by Integrated Pollution Prevention and Control (IPPC). Today, Integrated Product Policy (IPP) and eco-design of products with Directive 2005/32/EC have become a focus for individual companies.

- Priorities in energy:
 - Promotion of efficient energy use
 - Implementation of internalized costs
 - Labeling
- Priorities in industry:
 - Promotion of small and medium-sized companies
 - Promotion of life cycle-oriented product policy
 - Improvements in environmental impact control
 - Promotion of EuroBAT (Best Available Techniques)
 - Facilitate eco-business
 - Clean technology for small and medium-sized companies
 - Eco-efficiency in government–private partnership for innovation.

The 2005 issued directive 2005/32/EC for eco-design of products (European Union 2005) will accelerate this trend.

Currently, the sixth European Commission Framework program on the environment is in action, connecting European research activities of research institutes and industry in more than 108 Integrated Projects and 57 Networks of Excellence.

1.3.3 Swiss policy (Strategie des Bundesrates)

A clear policy for sustainable development was achieved only when an interdepartmental board was formed. In cooperation these offices have developed a clear strategy (Strategie des Bundesrates 2002), indicating the action fields at a first level.

[13] http://eea.eu.int
[14] http://europa.euint/comm/environment

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The areas for improvement and corresponding measures of the Swiss governmental strategy for sustainable development are:

- Policy of economy and public service
- Policy of financing
- Education, research and technology
- Social cohesion
- Health
- Environment and natural resources
- Urban and rural area development
- Mobility
- Development, cooperation and promotion of peace
- Methods and instruments.

The measures to be taken and how they should be implemented are shown in Table 1.1.

The Swiss Bundesamt für Statistik elaborated national indicators for monitoring, action fields and measures to be taken on a national level in a large research project (BFS 2003). The strategy also encourages local communities and industry to make efforts by means of a local Agenda 21 and environmental labeling. The attempted release of a CO_2 tax on energy by law is leading to voluntary actions by individual businesses to reduce their CO_2 emissions back to the level of 1990; so far, 22 textile companies have taken action on that voluntary basis.

1.3.4 Case study: the textile sector

When in 1994 the North American Free Trade Association (NAFTA) was founded, the US textile sector benefited from their new trade partners (Canada

Table 1.1 Principles of improvement in terms of measures and actions together with recommendations on how these actions should be taken

Measures	Recommendations
• Information and sensitivity	• Legitimate
• Setting criteria and methods	• Efficient
• International harmonization of standards	• Adequate
• Mutual acceptance of label systems	• International laws
• Certification of labeling organizations	• Non-discriminating
• Claim of authority	• Reliable
• Public procurement	• Transparent
• Creating additional legal framework conditions	• Integrated
• Financial support for private labels	
• Creation of governmental mandate	
• Scientific evaluation of label impacts	

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and Mexico). The US textile industry is located in Virginia, North and South Carolina and Georgia. However, domestic production declined steadily by 30% from 1996 to 2001, of which 12% was in 2001 alone. In the traditional textile state of North Carolina more than 25% of textile workers lost their jobs between 1988 and 1998, but when exports declined further in 2003, the loss increased dramatically to 25% of the 1998 employment level.

The US Environmental Protection Agency (EPA) developed best management practice for pollution prevention in the textile industry in 1988, focusing on main environmental impacts caused by the textile industry. There are limits for ejection of wastewater and surcharges if those limits are exceeded. After the Pollution Prevention Act of 1990 the EPA launched a program with an inventory of toxic release of the sector and recommendations on recycling and reuse (US EPA 1997). In this program, opportunities for pollution prevention are indicated by means of practical guidelines. The voluntary initiative 'Design For Environment' (DFE) addresses only the garment care sector and not the textile (production) industry. Research activities in private organizations like Cotton Incorporated and at universities do not show a focus on environmentally friendly product development.

Textiles and apparel accounted for 4% of value added but for 7% of employment in EU 15. The trade deficit in this sector in 2002 was 26.6 billion euro, to which apparel contributed a 34.1 billion euro deficit and the textile trade a surplus. In 2001 and 2002 production was reduced by 8.7% and employment by 8.4%: a tremendous loss for the economy and society. On the other hand the environment should benefit from the reduced amount and load of wastewater in production. In short, the EU textile industry struggles for its turn towards sustainable development. The sector needs to change its goals and structure, or shifts to other industrial sectors will be inevitable.

Environmental protection with the IPPC as a general aim has been transferred to specific goals for the textile and apparel industry with the BAT reference documents (BREFs[15]). Still, it is doubtful whether these documents are easy to apply by authorities, as most are not textile experts. The document shows some severe deficiencies and imbalances: although processes of the whole value-added chain are dealt with, emphasis is given to the finishing process. European COST Action 628 environmental index for textiles, best available techniques, has formed a task force for scientific evaluation and also investigated the practices in implementation. Significant missing parts were found such as a life-cycle perspective, information on legislation, and economic and social (educational) impacts. Furthermore, the information on fiber associated with processes is not balanced, there is no survey on research activities available, and perhaps most importantly there is no practical advice on environmental loads.

[15] http://eippcb.jrc.es/pages/FActivities.htm

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With the enlargement of the EU, many nations with traditional relations in the textile trade have become members. Two conferences on the future of the textile and apparel industry in the enlarged EU dealt with these aspects in 2003. Although the new political situation brings many advantages, there are also some economic challenges to be mastered. The new members bring a large textile work force (almost an additional third of the EU 15) but comparatively low added value. The employment of 2.7 million persons in the sector of textiles and apparel may not be possible in the future. Additional education of the employees in fashion as well as environmental protection will be necessary.

The textile sector in the EU 25 brings established partners into one trade union. The different orientation requires a restructuring of the sector within the EU:

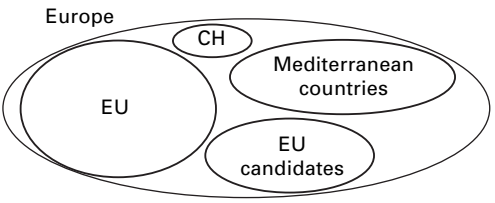
- New members are known to come from the passive finishing trade: 75–90% exported to EU 15, 45–75% imported from EU 15.
- The textile sector is important for new members, but so also are relations with non-EU neighbor states.
- There are additional costs for the required environmental improvements for new members (e.g. Guideline 96/61).
- New members lack experience in fashion (competitive disadvantage).
- There is a gradient from the EU 15 – new members: 10% value added by 60% more employees!
- Wages will increase in new member countries (competition from Asia).

In order to balance the strong pressure arising from Asian countries with low wages, new partnerships and clusters along the value-added chain of textiles and apparel will have to be elaborated, to retain competitiveness and maintain the status quo of employment. The key factors in achieving a sustainable textile industry will be development of new technology and thereby new products specifically of superior quality, but also for new markets in Asia and America (see Fig. 1.8).

European research supports environmental textile research in COST Action 628 on life cycle assessment of textile products, eco-efficiency and definition of best available technology of textile processing. Researchers from 11 European nations work together on the definition of an environmental index for textiles through harmonization of national environmental and quality parameters. This action has been highly rated also due to the cooperation with the industry.

Switzerland so far has not specified requirements for the textile industry, as the business is no longer a large one and represents only the seventh largest in the national economy. Swiss environmental legislation is considered to be among the strictest on the globe. However, an attempt to reduce the formal (not the material) requirement for legal compliance of SME in the

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- New cluster strategy to survive: broader geographic base
- New areas: technical/industrial textiles
 - non-woven (filters, hygiene fabrics, geo-textiles)
 - automotive, medical textiles
- New markets: quality, design, innovation and technology, value-added production
- Competition through outsourcing to countries with low wages (South and East)
- Growth in fabrics with added value necessary
- Environmental standards (OECD, UNEP)
- Protection against dumping prices

1.8 Trade in the European textile sector includes also the southern non-EU countries around the Mediterranean Sea. Europe is more competitive than the USA and Japan, but suffers high competition from China, India and Pakistan.

textile sector is being developed by the Bundesamt für Umwelt, Wald und Landschaft (BUWAL).[16]

1.4 Sustainability in industry

Regarding the three pillars of sustainable development, the economic rating of industry is well developed and defined by key figures, but no comparable criteria and indicators are developed for ecological and social aspects. Large companies may develop suitable indicators that are applied for product development (Section 1.4.2). International organizations are elaborating first criteria and indicators allowing global comparison (see Section 1.4.3). However, their effectiveness has yet to be proven in practice.

1.4.1 Tools for assessment and practice in industry

Industrial organizations such as the World Business Council for Sustainable Development (WBCSD) and the Club of Rome (Meadows *et al*. 1992) collected many case studies and developed guidelines and identified key drivers for sustainable development. Eco-efficiency became the term mainly applied in industry. Simple guidelines have had tremendous effects on product development and life-cycle thinking. Easy to apply eco-efficiency

[16] Personal information STV, BUWAL

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principles by the World Business Council for Sustainable Development (WBCSD) include:

- Minimize material intensity of products and services
- Minimize energy intensity of products and services
- Decrease distribution of toxic substances
- Increase recyclability of materials
- Maximize sustainable consumption of renewable resources
- Extend product life cycle
- Increase service intensity of products and services.

For the traditional economist such analysis bears completely new considerations, as fast growth used to be a key driver for economy. However, these guidelines aim to give a new direction for development. They do not evaluate improvements of the impacts caused by the individual product and service.

Companies are successful in the implementation of sustainable development only if they have strong moral support from the top management. By creating a culture of corporate identity, societal marketing or a philanthropic culture, entrepreneurs include sustainable development in their everyday business. Not only can they still benefit from the first-mover advantage in image against competitors, but also their process control increases and allows sound cost calculation. Consequently an integrated management system, including environmental and social aspects, is a precondition for such a culture. In Section 1.5 the implementation of impact assessment in practice is addressed.[17] Industry groups have started to define company guidelines for environmental product development (e.g. Siemens norm 36350-1[18]). Such concepts will become more important under the current EU directive for product development (European Union 2005), and the aspect of sustainability rating (see Section 1.4.4.) represents another incentive for companies.

1.4.2 International organizations

International organizations such as the World Watch Institute[19] and the World Bank[20] collect general environmental information and offer an available (Internet) source of data. If environmental impacts from industry are rated over years, we can see the areas of improvement: in many parts of Europe, in some parts of the Americas and only in a few parts of developing countries.

[17] ISO 14000 ff
[18] http://www.igexact.org/agu/index.htm
[19] http://www.worldwatch.org
[20] www.worldbank.org

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Hence the greatest potential of growth is in Asia and our concern should be in this region.

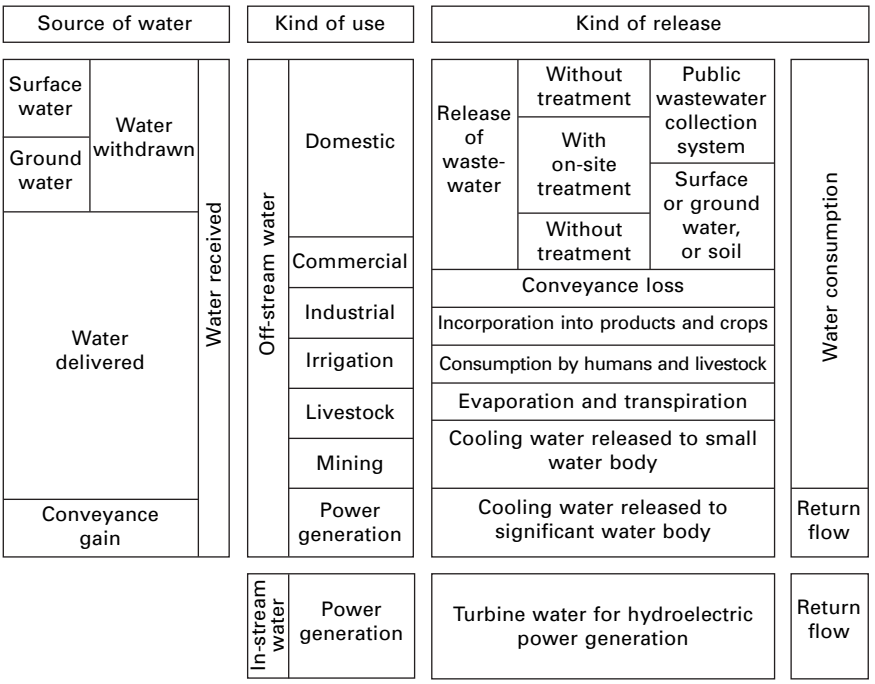
The International Chamber of Commerce[21] was one of the first organizations to develop criteria for sustainability in their business. Since 1992 many other industrial and commercial organizations have involved the new strategy of sustainable development in their activities.

Environmental information, combined with knowledge from industry, industrial and business sectors or management systems, may be used by other organizations to create indicators and criteria as well as entire programs for sustainable development. The United Nations Organization is active in two fields. Under UNEP (United Nations Environmental Program[22]) programs for global, environmentally compatible industry are developed. Many of its publications deal specifically with industrial sectors like textiles or leather. Particularly in developing countries not only industry, but to a higher extent public and private businesses, contribute a great deal to the pollution of the environment. UNIDO (United Nations Industrial Development Organization) as well as UNCTAD (United Nations Commission for Trade and Development[23]) provide manuals for industry. In the latest manual, *Eco Efficiency Indicators*, it is proposed to monitor the five indicators water, energy use, global warming potential (GWP), ozone depletion potential (ODP) and waste. While the requested information is very detailed for some aspects such as water (see Fig. 1.9), other indicators show overlap (such as energy with GWP). The criteria are based only partly on international agreements (the Kyoto Protocol for the GWP and the Montreal Protocol for ODP) but neglect the Basel convention[24] as a criterion for trade with waste (developed by UNEP).

Some agreements developed within international organizations become mandatory as soon as the member nations agree on them. The most important may be the WTO 2005 and the much lesser-known Aarhus convention.[25] Under the World Trade Organization (WTO) agreements for sustainable development of global trade are to be negotiated. The driving forces are different for industry and agriculture (see Chapter 5). The United Nations Economic Commission for Europe (UNECE)[26] developed the Aarhus convention on 'Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters'.

[21] www.iccwbo.org
[22] www.unep.org/
[23] www.unctad.org/
[24] www.basel.Int/
[25] www.unece.org/env/pp/documents
[26] www.unece.org/env/pp

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1.9 Detailed proposition by UNCTAD for the 'Water Criterion' as one of the five criteria: water, waste, energy use, global warming potential (Kyoto protocol), and ozone depletion potential (Montreal protocol). The disadvantage of the system is the missing execution of the Basel convention (ban of trade with waste). 'Conveyance' is the volume of water flowing through the branch to the user multiplied by the loss factor.

1.4.3 Textile and apparel organizations

Among industrial organizations, 'Responsible Care'[27] was one of the earliest actions towards an environmentally responsible chemical industry in many nations. The chemical industry can be considered as main supplier for the textile industry.

The US Office of Textile and Apparel (OTEXA[28]) and the American Apparel and Footwear Association[29] provide no policy or strategies for environmental protection. Apparel Retail recommends an 'environmental code of conduct' to be audited by the company, especially in international sourcing.

[27] www.cca-chem.org/rcreport
[28] http://otexa.ita.doc.gov/
[29] http://www.osha.gov/dcsp/alliances/aafa/aafa.html

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The European Apparel and Textile Organization (EURATEX[30]) pushes the idea of sustainable development by communicating an environmental policy besides legal and social affairs. In its mission as a representative of the world's leading exporter for textiles and the third largest for clothes, EURATEX commits itself to the *image of an innovative, environmentally responsible and dynamic industry at the service of its customers*. It also strongly supports international research on textiles in the European Commission's framework programs for sustainable development[31] and COST actions.[32]

The Swiss Association for Textiles (TVS) has published eight chapters on textiles and the environment[33] and focuses on sustainable frame work conditions for domestic textile production. Simple and practical guidelines have been developed by many other industrial organizations.

1.4.4 Sustainability for credit rating

In the 1990s it became apparent that companies with so-called green funding (reported by Netherlands organization NOVEM[34]) show better economic performance than the average of all companies being funded. This was certainly one of the reasons why financial institutions started to deal with sustainable development as a criterion for long-term investment. However, the term sustainability rating is applied in two different ways. The Dow Jones Sustainability Index (DJSI) includes economic, ecological and social aspects in its rating, while the SIRI[35] investigates ecological and social aspects apart from economic aspects. Under the DJSI a World Index including over 300 best companies (10%) from 26 countries and a pan-European Index, the STOXX Sustainability Index, including 167 best companies (20%) from 12 countries, are rated annually. The regulative base for both rating systems is the Basel II convention, obligating also SME to disclose their sustainable performance. However, the database of the DJSI's three pillars cannot be taken as equivalent as the parts of the underlying questionnaire consist of 11 pages for economic, three pages for environmental and nine pages for social data. Although the rating includes the formation of quantitative goals, the inventory does not require information on airborne emissions or replacement of non-renewable energy. Furthermore the formulations of measures to be taken in order to achieve the goals are not included in the rating system.

As a by-product, 'sustainability reporting' with stringent criteria is being

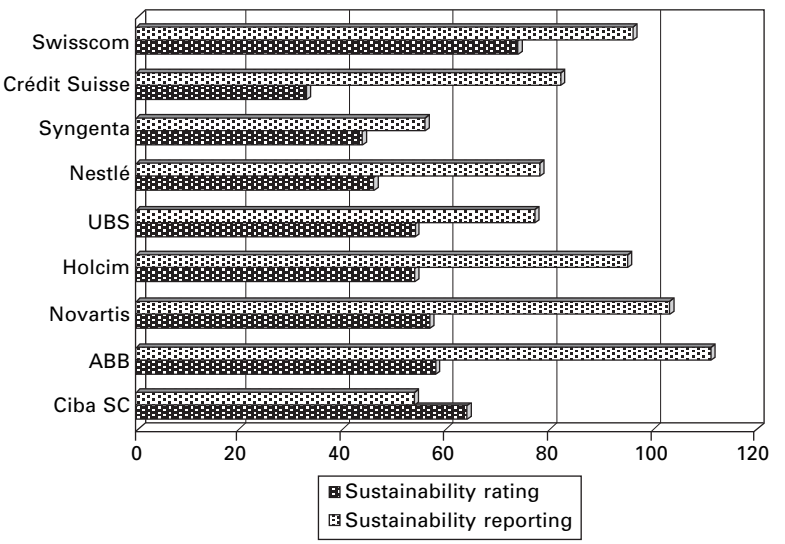
[30] http://www.euratex.org/content/environment.html
[31] http://europa.eu.int/comm/research/fp6/index_en.html
[32] http://cost.cordis.lu/src/home.cfm
[33] http://www.swisstextiles.ch/de/index.cfm
[34] www.socialfunds.com/news/article.cgi/article395.html
[35] http://www.siricompany.com/

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applied, showing yet another image of a company's performance. Interestingly the rating and the reporting systems do not have to be in accordance, as Fig. 1.10 shows (Tobler 2005b). Such rating will become more important as soon as the Aarhus convention (see Section 1.4.2) is implemented. Figure 1.11 shows the three dimensions of the above-mentioned systems. It becomes evident that the performance in the three dimensions must remain within a certain frame, according to the optimizing principle. If only two dimensions are rated, the performance of an individual dimension may be maximized, yet this is not sustainable.

1.5 Environmental management systems

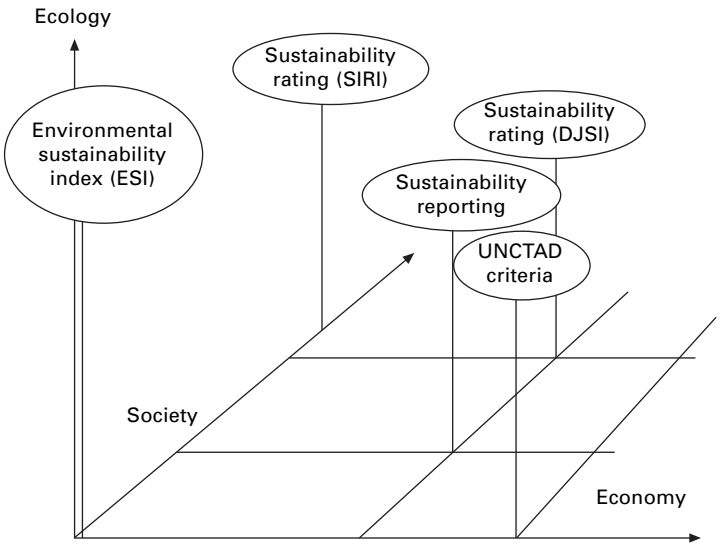
Many companies have seized the opportunity to become proactive in environmental concerns. Concepts like 'business excellence'[36] or simply long-term economy set a benchmark in including environmental impacts and their consequences into business. Others following national legislation have claimed unfair competition towards countries with lower legal requirements. Some globally operating companies (Siemens, Novartis, duPont, etc.) have taken action to set even more advanced environmental and/or social standards



1.10 Comparison of sustainability rating (SIRI) and reporting. Most Swiss companies presented here perform good marketing of their environmental orientation but show inferior ratings by means of the SIRI (see also Fig. 1.11).

[36] Defined by the European Foundation of Quality Management (www.efqm.org)

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1.11 Indicator portfolio. UNCTAD criteria (economy and ecology rated). SIRI (Swiss market index) ecology and social aspects rated. DJSI (Dow Jones Sustainability Index): economy, ecology and social aspects rated.

than the legislation of their home countries specifies and to establish them worldwide within the company.

Each environmental management system (EMS) aims to prevent and systematically reduce environmental impacts generated by any processes carried out by a company (or an administration). General elements are (a) environmental guidelines, (b) impact assessment by measurements, (c) setting of quantified goals and corresponding action plans, (d) implementation, education and control, and (e) management review. There is no level given, but continual improvement is to be achieved. The systems are generally not specified for a specific business sector, e.g. textiles, building materials or food, but there are a few exceptions, like Eco-Tex 1000 (see Section 1.5.4).

1.5.1 International management systems: ISO 14000

Based on British standard 7750, the ISO 14000 Environmental Management System[37] has been applied in many companies worldwide. Among the nations, Japan shows the fastest growth of these systems, followed by Europe. US companies do not participate in the system in proportion to their magnitude. In Europe ISO 14000 has been applied in many companies and

[37] http://www.iso.ch/welcome.htm

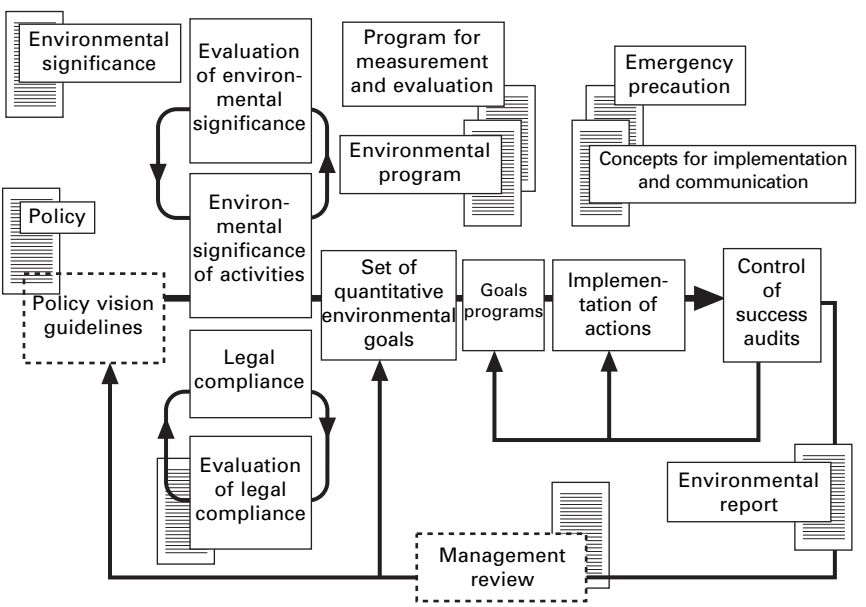
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has even been specified for farming. The required milestones as shown in Fig. 1.12 are environmental guidelines, analysis/measurement of potential environmental impacts (associated with their significance), quantified goals for improvement, an action plan and control, education of employees, reporting and management review.

Key analyses are the so-called significant environmental aspects (Fig. 1.13). All potential environmental impacts have to be identified by means of a systematic process analysis. The impacts are evaluated in practice according to their magnitude.

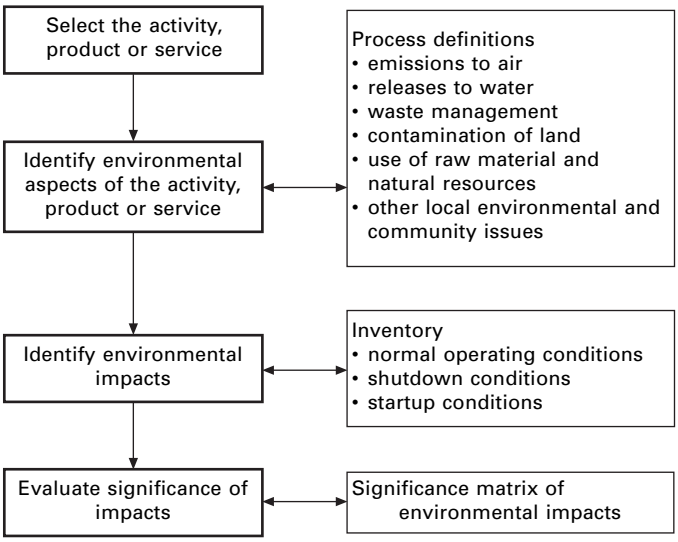
ISO 14000 has developed this general schedule of an EMS and requires as a starting point the 'legal compliance' of the company's activities, whereby evidence has to be collected on legislation at all levels (national, regional and local) and the company has to prove its legal compliance. The certification is achieved by a system audit through an accredited auditor of a private audit company. The accreditation system is controlled by national offices and the Centre Européen des Normes (CEN) (see Fig. 1.14).

Certification is restricted to the audited locations of a company. Regular internal audits help the company to maintain control of the system. The process-oriented quality management system ISO 9000 allows a perfect match with ISO 14000. Generally, companies (in the textile business) have to

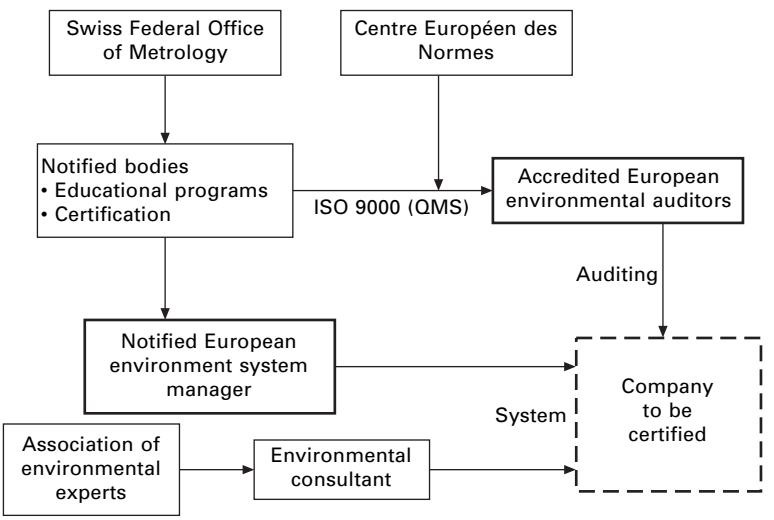


1.12 Elements of the ISO 14000 environmental management system are arranged in an annual procedure. Many documents are required for certification, sensitization of employees and review of quantified goals.

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1.13 Environmental aspects are investigated with ISO 14000 and evaluated according to their environmental significance.



1.14 The organization for certification of ISO 14000 under the European center of norms: certification of companies by means of accredited auditors. Environmental knowledge can be enhanced by capacity building (larger companies) or recognized consultants (SME).

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fulfill safety requirements[38] to integrate their system in the ISO management system. The result of such an integrated management system is process control in technical, economic and environmental terms. Under today's pressure by competition, companies can hardly exist without an integrated system (including ISO 14000) – some companies even require one from their suppliers. With DEVECO[39] ISO supports developing countries to join the system.

1.5.2 The EU specialty: EMAS

The Environmental Management and Auditing Scheme (EMAS)[40] is the first environmental management system available since 1994, based on British Standard BS 7750. It has been developed for the EU only. Consequently no location outside the EU can be certified with this system. EMAS is in general accordance with the requirements of ISO 14000 with the addition of two elements: the environmental report and an audit by authorities (see Table 1.2). These additional points make it more attractive for EU countries that wish to have a certain governmental control over environmental activities in the industrial sector. As a third difference, the labeling practice can be mentioned, whereby EMAS provides EU labels (with criteria developed and

Table 1.2 The European Union has developed the Environmental Management and Auditing Scheme (EMAS), based on auditing by authorities and an environmental declaration. The ISO system also develops tools and standards for environmental evaluation

	European Management and Auditing Scheme	International Organization for Standardization
Short cut	EMAS	ISO 14000 ff
Introduction	1994	1996–2000
Validity	EU location	Centre Européen des Normes
Certification	Audit by authorities	Environmental audit by notified body
Information	Environmental declaration	–
Policy elements	Environmental policy	Environmental policy
	Environmental program	Environmental Management System, ISO 14001 Life cycle assessment (LCA), ISO 14040 ff Environmental Performance Evaluation (EPE)
Data	Data in management system	Environmental key figures
Labeling	EU label	ISO label types I–IV (ISO 14020 ff)

[38] Safety and occupational health (USA), Maschinenrichtlinie (EU), EKAS Richtlinie (Switzerland)
[39] www.devecocorp.com
[40] http://europa.eu.int/comm/environment/emas/index_en.htm

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controlled by authorities) and ISO provides four individual types of labels (see Section 1.5.3).

1.5.3 Non-certified systems: societal marketing

There is a variety of non-certified EMS established by companies or in cooperation with research institutes. Kotler and Armstrong (2001) describe the American type as 'societal marketing' while the US EPA indicates different certification programs (see Fig. 1.12). Many Scandinavian countries have established EMS in cooperation between industry and government.[41]

1.5.4 Textile environmental management systems (EMS)

One textile-specific environmental management system, Eco-Tex 1000, is known in Europe, but its propagation is not widespread. Eco-Tex 1000 is an improvement on Eco-Tex 100 product labeling (see Section 1.6), including the production site of the labeled products. However, the system does not include continuous improvement as required by ISO systems. The Hohenstein Institute[42] in Germany, an international textile research institute, has defined and developed certain levels of environmental impacts. The products are certified by authorized national private companies or laboratories. Today only a few dozen companies worldwide fulfill the requirement of Eco-Tex 1000.

1.6 Environmental labeling

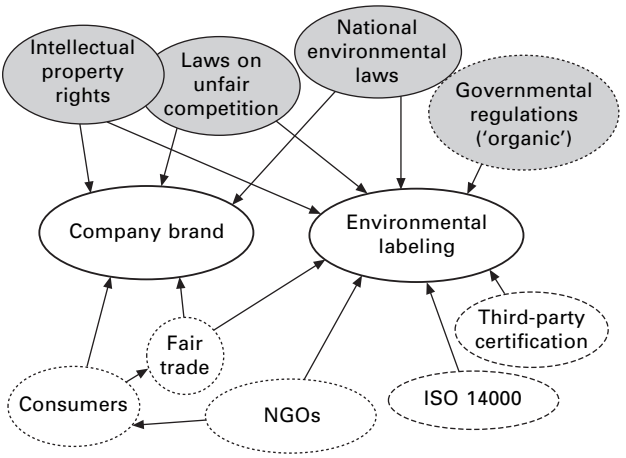
Environmental labeling has become popular in businesses such as food, clothing and building materials. Although called environmental labels, they do not necessarily represent strictly environmental criteria. They can be considered as an answer to the multitude of requirements and expectations from governments, non-governmental organizations and consumers in a competitive environment (see Fig. 1.15).

However, the differentiation to a company's brand often is not evident to consumers. In many cases a company's reliability is high enough to go for a private (environmental) brand. Such a strategy is not aligned with the requirements of ISO (see Section 5.1) and lacks transparency and comparability. Nevertheless private environmental brands are often very successful for textile companies (see Fig. 1.16).

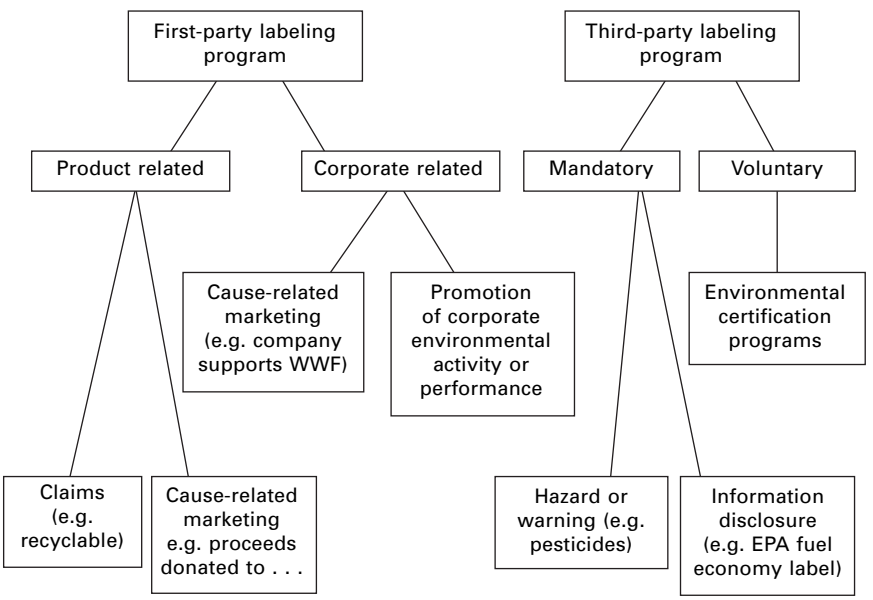
Under sustainable development we have to study economic and social aspects too, besides environmental aspects. Any study investigating

[41] http://www.emsc.ch/Deutsch/index.htm
[42] www.hohenstein.de

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1.15 Environmental labeling compared to company branding. The two product types have to satisfy the requirements of legislation (gray) and society's values (white). Environmental labels additionally need to meet standards (by regulations and/or organizations).



1.16 Environmental labels are differently focused according to the company's culture. European labels are often product related or voluntary, while American labels are more corporate related or mandatory.

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customers' buying decisions names price as the most important criterion, and it is needless to mention the economic aspects. We may assume economic aspects are considered, even if a real cost analysis is not performed by many SMEs. All activities of companies in a market-driven society have to be economically profitable. Most of them are not on short-term return but on a long-term strategy. According to customers' value settings, different criteria may become important for a buying decision for food, clothes or building materials. Thereby information provided by the shop, such as labels, code of conduct or certified management systems, supports the decision. The Clean Clothes Code of Conduct[43] lists the following:

- Voluntary: no forced labor (ILO conventions 29 and 105)
- No discrimination in employment (ILO conventions 100 and 111)
- No exploiting child work (ILO convention 138)
- Respect the right of alliances and the right for negotiation of wage agreements (ILO conventions 87 and 98)
- Payment of adequate wages
- Work time not too long
- Humane working conditions
- Employer and employees define a permanent relation in occupation
- Independent control authority established.

Influences, therefore, can be seen from health criteria, especially for food but also for clothes and building materials, because allergies have increased in populations and are continuing to grow.

Another social issue is working conditions of employees, mainly in developing countries and emerging economies. Activities like the 'clean clothes campaign'[44] and 'let's stitch together' are targeted to that issue to foster proper working conditions by setting standards in agreement with the ILO (see Fig. 1.17). The campaign was carried out in Switzerland by mobilizing customers to send prepared postcards to retailers, asking them what working conditions their workers in the supply chain were warranted. Companies were flooded with large numbers of postcards all asking the same. Retail and wholesale companies may also establish a Social Accountability 8000[45] certification in the management system of the supply chain.

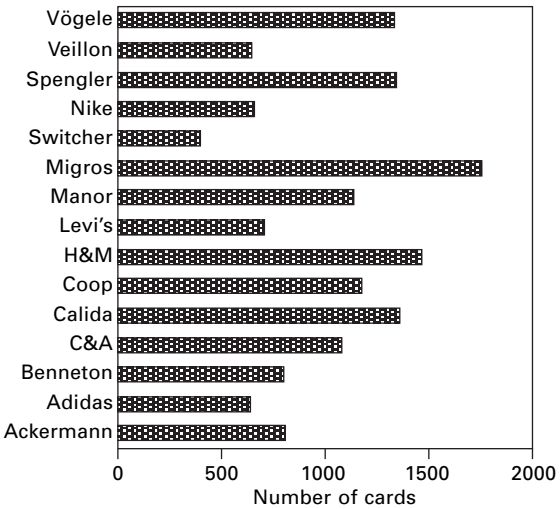
Labeling cultures and environmental awareness concerning consumer goods are different in different nations. Positive communication, showing the benefits of labeled products, is more popular in Europe, while the USA prefers different strategies: neutral, negative and positive communication in

[43] http://www.cleanclothes.ch/d/

[44] Activity generated by the NGO Erklärung von Bern (www.evb.ch and www.cleanclothes.ch)

[45] www.sa-intl.org

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1.17 Clean clothes campaign: number of cards sent by consumers to individual companies.

environmental labels. So-called negative communication mainly consists of warnings of improper use, e.g. giving information about toxicity, etc. The reason for this may be found in the considerable number of mandatory label programs in the USA (seven among 19 programs), while all 31 European labeling programs are voluntary.

Behind these practices in the two continents stand two completely different legal systems and levels of environmental awareness. Europeans are certainly more active in environmental protection as can be concluded from the political parties in European governments. Caring for the environment is more anchored in European activities than in the activities of US citizens. A damaged environment represents a lower quality of life for Europeans, while Americans mainly still consider quality of life in terms of economic benefit.

1.6.1 Textile labels

Textile companies have recognized very early the power of labeling, particularly in the form of trademarks for some natural fibers. The best known labels are the Woolmark, Cotton and Silk for communication with the customer. The European Union and Switzerland require information on fiber content (see Fig. 1.18). Additionally, apparel is often labeled with information on care properties (voluntary for Europe, mandatory for USA) as well as origin of production. The latter can be manipulated by allocating some processes in a third country in such a manner that customers get no unambiguous

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Regulation on material composition*
e.g. a product is made of 72% cotton, 7% polyester, 7% silk, 7% viscose, 7% acetate, but you read:

72% cotton, 28% other fibers

International labeling on care properties
(EU: voluntary, USA: mandatory)
- washing temperature
- bleaching with chlorine
- dry cleaning
- ironing temperature
- tumble drying

➔ Consumers cannot deduce care parameters from composition of raw material

*Bundesgesetz über technische Handelshemmnisse THG, SR 946.51

1.18 European requirements on declaration of material and care properties. In the US the declaration of care properties is mandatory (in order to prevent claims).

information. The new category of environmental labels adds to the labeling confusion and is not easy to understand by the customer. Therefore attempts have been made by governments to set standards or launch programs.

Textile labels are very prominent among environmental product labels for consumer goods. Communication is not as simple as with electrical and electronic devices, where energy consumption represents the main environmental impact.

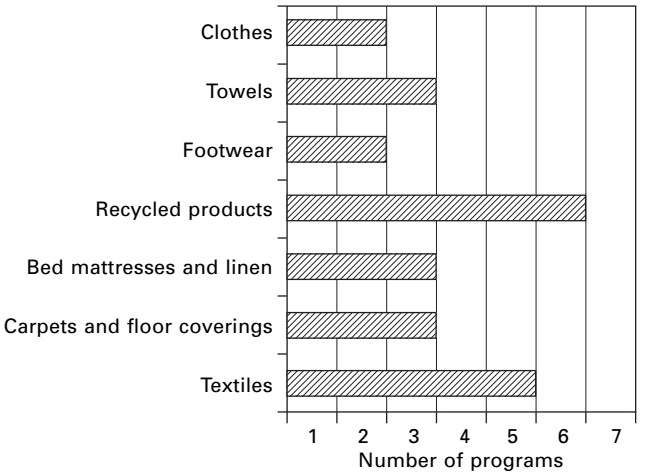
Environmental labels and labeling programs

About two dozen national environmental textile programs are known worldwide, and the number is increasing (see Fig. 1.19). Particularly Asian countries, where global material flows end in a sink, have been encouraged by their governments to establish environmental programs and labels, while in Europe the action was taken more by private companies.

Table 1.3 lists some of the most common environmental labels for textiles in central Europe. A selection of labels is given in Fig. 1.20. European companies had to decide whether to work with an environmental program (in compliance with governmental requirements), an ISO label (certified by an accredited body), a governmental label (the EU flower), a private textile label (certified by a third party), or even with a private brand according to the company's environmental standards. The European Union concentrates on the EU flower and enhances support activities in Asian countries to build up capacities in LCA and eco-design.[46] The American continent has only

[46] Seminar on LCA and Eco Design for textiles in the framework of EU–Thailand economic cooperation small project facilities

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1.19 Eco-labeling programs for textiles worldwide.

Table 1.3 European textile labels

Öko Tex 100, 100+, 1000	Birgit Steilmann
EU Flower Label	Bio Baumwolle
AKN	KRAV
Hess Natur	Eco by Migros
Natura line by Coop	Green Cotton
Skal	

a very marginal share of environmental textile labels compared to Europe and Asia.

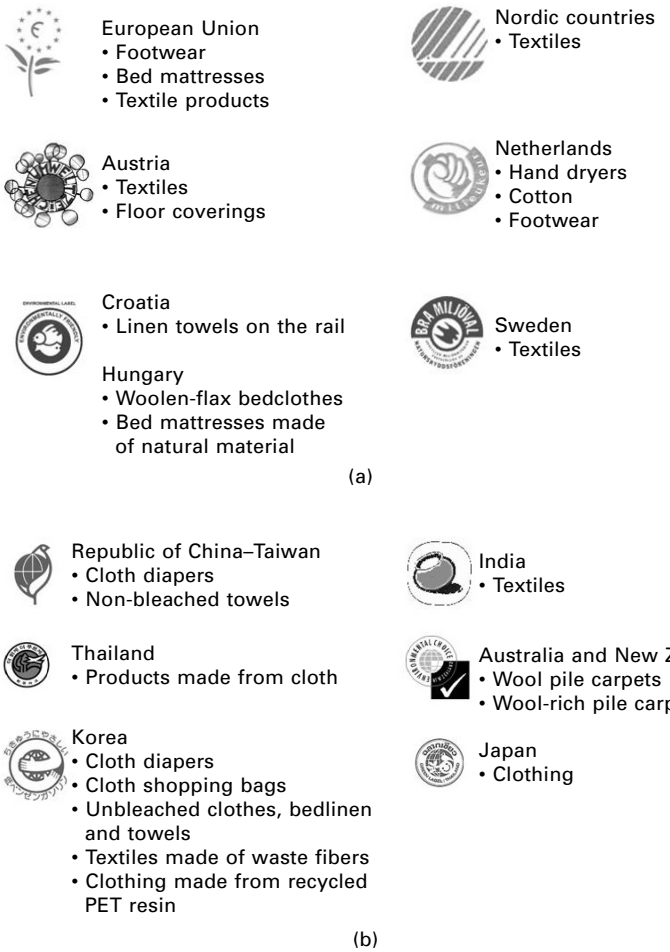
Mandatory textile labeling

A specific situation occurs in labeling ecologically grown cotton. Several companies have pretended to work with such cotton for many years. In the 1990s the European Union as well as Switzerland launched governmental programs for 'organic' agriculture based on legislation (EC 2092/91 and the Swiss Bio-Verordnung respectively). Since then, organic cotton has to be certified according to the legislative norms by an accredited body, and thereby proven to be compliant with mandatory requirements (see Table 1.4).

Labels and life cycle

The great variety of textile products makes it difficult to set definitions or standards for labels. Very often arbitrary aspects from the product's life cycle are selected and their environmental performance communicated to

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1.20 Textile label programs from (a) Europe and (b) Asia and Australia.

the customer. Sometimes significant stages like fiber production are not represented with any information (see Fig. 1.21).

Even within specific processes like fiber production or finishing processes there are huge differences between standards for individual eco-labels (Table 1.5). While some eco-labels provide information only about raw material and cultivation type, others also include social aspects in agriculture, addressing sustainable development with the economic and social welfare of developing countries.

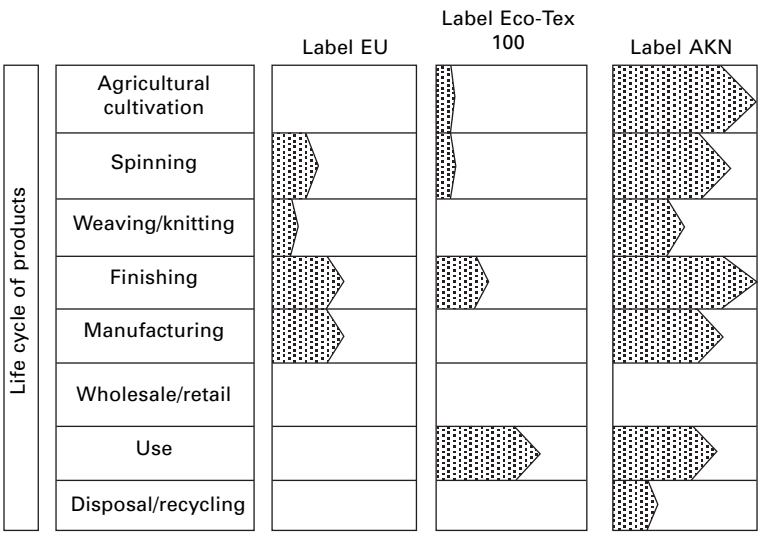
Finishing processes with their large variety of technologies and formulas certainly bear one of the highest potentials for environmental impact reduction.

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Table 1.4 Compliance and certification of labels with regulations

Eco-label indicating status	Example	Commercial/legal certification
Compliance with mandatory European or national standards	EC 2092/91 'bio' 'ecological'	No charge, national law, accredited body
Compliance with mandatory European or national standards	Labeling program EC: T-shirts	No charge, national law, accredited body
Compliance with third-party proprietary standards	Eco-Tex 100 AKN*	Charge for approval, registered trademark, accredited body
Compliance with proprietary company standards	Coop Natura Line* Hess Natur*	Company ownership, registered trademark, accredited body
Compliance with proprietary company standards	Green Cotton*	Company ownership, brand name

* = brands.



1.21 Environmental labeling systems and their representation (requirements) of a life cycle approach.

As presented in Table 1.6, indicators addressed by environmental labels are not harmonized, and the limits for emissions are unequal.

The average customer, having no sound knowledge of production processes, cannot make an objective decision on the 'environmental friendliness' of a product. He or she is swamped with the information given by an environmental

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Table 1.5 Comparison of standards in cultivation. Some labels include also social standards besides environmental requirements

	Cultivation	Declaration of raw material	Social aspects
EU label	No restriction	Polyester accepted, cotton >50%	
Skal	EU standard 2092/91 (kbA*)	Organic only	Social declaration
KRAV	EU standard 2092/91	A > 95% organic B > 75% organic	Social declaration, decertification possible
AKN members	Also mechanically, pesticides < 0.l mg/kg	100% cotton	National and international human rights
Eco-Tex 100	Pesticides <1 mg/kg	No toxic agents	
Coop Natura Line	EU standard 2092/91	kbA*	Social standards
Migros/M-Sano	No restriction	Declaration of fiber origin	
Hess Natur	EU standard 2092/91 and handpicked (IP)	kbA* and handpicked	Proprietary choice of fiber anthroposophical guidelines

*kbA = controlled organic production.

Table 1.6 Selected parameters in finishing processes. Comparison of standards reveals differences in environmental requirements

	Desizing	Bleaching	Dyeing
EU-Label		If chlorine: AOX < 40 mg/kg	No carcinogens
Skal	LAS, polyglycolether, fatty alcohols	No chlorine oxidation/reduction	Vegetable or mineral, no heavy metals
KRAV	Easily degradable or 75% recycling	No perborate or hypochlorite	No heavy metals, no urea
AKN Mitglieder	90% degradable or 80% recycling	No bleaching	LD 50 < 2g/kg, eco-toxicity < 10
Eco-Tex 100		No bleaching with chlorine	Limits for heavy metals
Coop Natura Line	Biodegradable soaps and tensides*	No chlorine, chlorine dioxide or sodium hypochlorite	No heavy metals, no AOX
Migros/M-Sano	Control of desizing	Bleaching without chlorine	Min. heavy metals, LD 50 = 0.2 g/kg
Hess Natur	Biodegradable soaps and tensides*	Reductive or peroxide bleaching	No heavy metals, non-toxic

*See Section 2.9.2 in Chapter 2.

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label. Consequently the responsibility lies in the company's reliability, which can best be proved by external control of standards.

ISO labels and environmental product declaration

ISO 14020:2000 gives distinct requirements on the principles of environmental labels as follows:

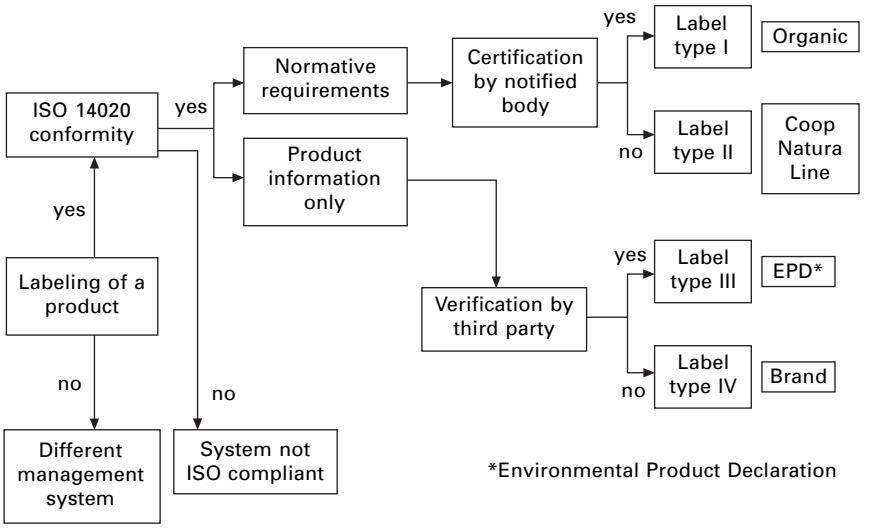
- Testable, objective, not deceptive
- Procedures and requirements without unnecessary obstacles for international trade
- Based on scientific methodology according to the demands. Precise and reproducible results
- Consideration of the entire life cycle of products and services, where deserved
- No obstacles for sound environmental innovations
- Reduce administration and information on necessary and useful criteria for agreement
- Procedures for development by consulting the interested people involved, search for consensus
- Provide sales departments with information on environmental aspects of products and services
- Provide interested people involved with information concerning procedures, methods and criteria used.

Emphasis is set on fair trade, transparency and consumer information.

ISO also developed a system for label types according to the compliance with ISO standards (ISO 14020 ff) or other standards (see Fig. 1.22). Following the outlined decision path, it becomes evident to customers how reliable a label is. Label type I is the most stringent as it is controlled by government and infringement with these standards means violation of law. Label type II is embedded in the framework of ISO 14000, certified by accredited bodies – another stringent procedure. If only product information is given, differences can be very great. The 'Environmental Product Declaration' (EPD) according to ISO/TR 14025:2000 requires life cycle-based information on the product, in other words life cycle assessment (LCA), a laborious task requiring expert knowledge in textile technology as well as environmental sciences. Certification by an independent party is a prerequisite. Consequently EPD is hardly found in textile products with their inherent limited lifetime. A European research consortium is elaborating an index for textiles, based on simplified LCA, to be recognized as a matrix for EPD.

The simple brand can be a reliable certification to some consumers, and this relation has been used by many companies. However, as there is no control, even the company must have difficulties in maintaining such 'standards'.

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1.22 ISO label types.

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2
The supply chain of textiles

Abstract: A survey on the whole textile chain is presented here, starting with fiber production and its variety depending on raw material, followed by textile processing and technologies in yarn and fabric production, further finishing processing and technology, then manufacturing and merchandising, and finally consumption, use and disposal. Simple descriptions of production stages allow insight into processing and understanding of interactions along the value-added chain, as well as their associated environmental indicators. Especially consumption and use, with their aspects of fashion, comfort and special properties, show how consumers, textile managers and authorities can develop strategies for personal choices or for management and legislation.

Key words: fiber processing, fabric production, textile finishing, textile care, environmental indicators.

This chapter provides basic information

- for (marketing) managers, who develop strategies towards sustainable development
- for farmers, because they are the people who grow plants and care for live stock on our planet
- for fiber producers and the textile industry in which sustainability is the target for optimization of processes in the value-added chain
- for authorities, who deal with sustainable development in the textile industry
- for people in fashion and design (to make dreams not only come true but also to be sustainable)
- for excellent sales persons, who wish to advise consumers
- for all interested consumers, young and old, who want to understand and learn and build sustainable values in society.

2.1 Introduction

Unlike value-added chains for food or building materials, textiles and apparel include a great number of process stages, carried out by different successive industry units. Along with the material flow, the value-added chain is modeled in the steps of fiber production, spinning, weaving/knitting, finishing, cutting and sewing, merchandising, wholesale/retail, consumption, and disposal/recycling. However, communication and driving forces are no longer aligned with this flow, because inputs from the market and product

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development are generated in design and merchandising, driven by signals from the markets. With this 'broken' perspective, the first steps, from fiber production up to the finished fabric, are considered as the supply chain. In simple terms, technology and quality are adequate parameters to support the flow of materials for the supply chain. If not integrated-produced (in which spinning, weaving/knitting and finishing are carried out in one company by a single commercial entity), finishing of textiles occupies a very special position in the supply chain, as the fabric is processed by subcontractors without ever being owned by the finishing company.

In this chapter the processes of the supply chain are outlined and contrasted with consumption and disposal/recycling processes. This chapter is meant as an introduction and overview for a basic understanding without giving detailed information about process technology, which is given in Chapter 3.

Fiber material is either grown in agriculture (animals and plants) as renewable resources or gained from fossil resources (crude oil). Whereas natural fibers have to be harvested and prepared for yarn formation (spinning), man-made fibers have to be chemically extracted from crude oil fractions or other natural resources before they can be spun. Consequently, spinning processes for natural fibers show significant differences compared to spinning operations in man-made fiber production.

The next step is the conversion of the one-dimensional material (yarn) into a two-dimensional material (fabric), achieved mainly by weaving or knitting in a mill. Non-woven fabrics may also be found in linings of apparel, but their main application is in automotive interiors, disposables and technical textiles. In dyeing and finishing, a variety of processes, specifically adapted to the raw material and the desired properties, are carried out. The main sections are pretreatment (cleaning and preparation), dyeing or printing, and finishing, where surface properties of fabrics are treated. Spinning, weaving/knitting and finishing are often carried out in individual companies, which are highly specialized in the individual processes. However, some companies are integrated as they are equipped for all processes. Consumers contribute through their preferences for particular materials and their individual behavior in use, and through their concerns for sustainable or non-sustainable living measurable, e.g. with the 'ecological footprint' by WWF. Their impact is considerably higher than impacts in production. Recycling of textiles and apparel is individually organized in different nations. The Swiss system is given later as an example. Two case studies on material recycling (polyester and nylon) complete this chapter.

2.2 Natural fibers

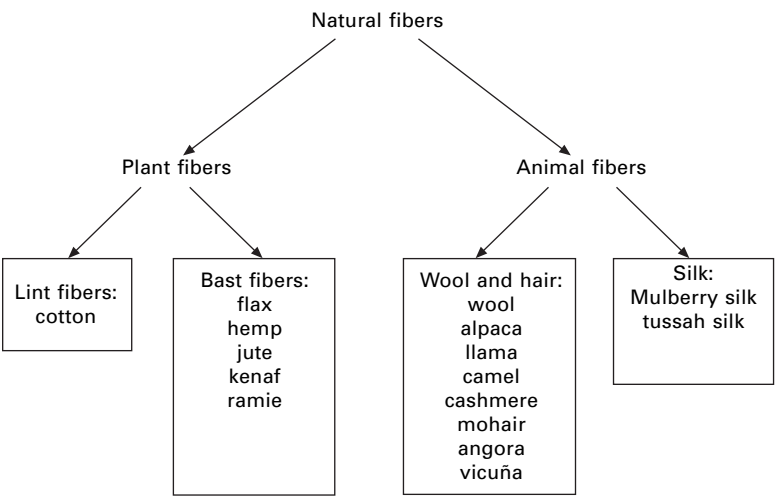
Today an ever-increasing variety of fiber material is applied in the production of textile fabrics. The main categories are natural fibers, gained either from

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plants that were once wild but are now grown in agriculture, or from domestic animals, often as a by-product of keeping them for food. The variety is very large (see Fig. 2.1), although some natural fibers are available only in limited quantities.

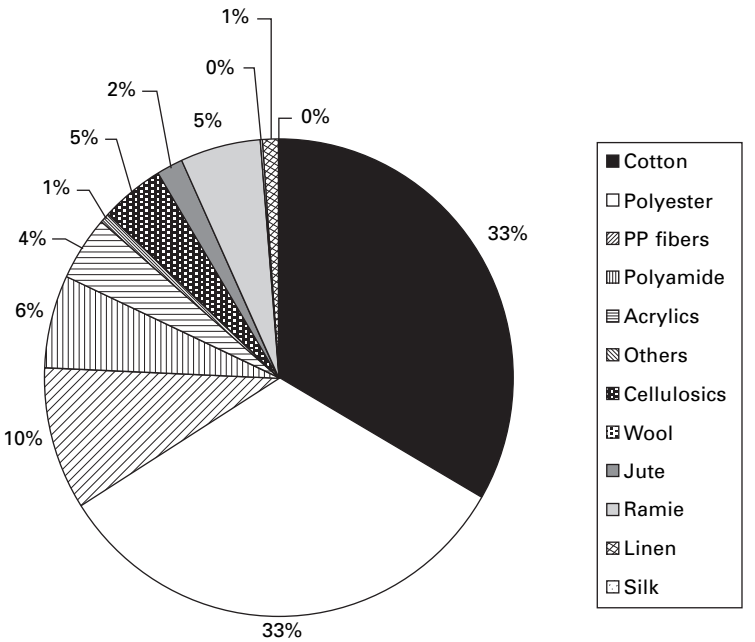
Natural fibers are gained from plants as lint or bast fibers (cotton, ramie, hemp) or from animals as hair (wool, cashmere, alpaca) or as filaments from silk. 'Man-made fibers' may have a natural cellulose base (viscose, cupro) or protein base from plants or animals (polylactate), or they are derivatives of crude oil fractions (polyester, polyamide, polypropylene, polyurethane). This book is focused on plant fibers (cotton), animal fibers (wool), 'man-made' cellulose fibers (viscose) and 'man-made' synthetic fibers. Whereas cotton and wool grow in a length determined by species and variety, the so-called staple length, all man-made fibers are produced as filaments (endless fibers). The only natural filament is silk, the spinning material produced by the glands of the silk spider. An overview of annual fiber consumption is given in Fig. 2.2.

Historically, textile fabrics in Europe were produced from domestic fibers such as wool, hemp and linen. These fibers were early supplemented by imported silk from China for luxury fabrics, and later by cotton, mainly from the New World. When the United States of America became independent of the Old World, they based textiles mainly on their domestic fiber, cotton. The magnitude of the natural fiber base has shifted in the last two centuries, and wool was replaced to a large extent by cotton in the nineteenth century. As consumption grew further, natural fibers were supplemented and replaced by man-made fibers in the last century (see Table 2.1). Since the middle of the



2.1 Natural fibers can be harvested from plants or animals. Except for silk, all are staple fibers.

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2.2 The world production of textile fibers by mass shows two dominant resources: polyester and cotton, both with a share of 33%.

Table 2.1 The history of fiber supply is characterized by a replacement of wool by cotton in the nineteenth century and a shift towards man-made fibers in the second part of the twentieth century

Year	Wool	Flax/linen	Cotton	Man-made fibers
1780	78%	18%	4%	–
1900	20%	6%	74%	–
1991	5%	–	47%	48%

twentieth century, man-made fibers have increased their share dramatically from an inferior artificial 'substitute' in wartime to a high-quality fiber with refined properties. Today we have a split of raw materials with an increasing amount and diversification of man-made fibers. The development of the fiber base is shown in Table 2.1.

The raw material for much apparel consists of a blend of different fiber materials, either to improve the properties of fabric materials or to reduce costs. The blending of raw materials may be achieved at different stages of yarn production or in the weaving process. Blended fabrics require multiple or combined processes in dyeing and finishing.

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2.2.1 Cotton

Cotton is the most important among the natural plant fibers and land for cotton cultivation covers large areas of the planet. Due to climate, the growing areas are limited to a belt of 30° south and north from the equator (see Fig. 2.3). The largest cotton producing areas are located in the USA, China, Paraguay, Mexico, Pakistan, Australia, Brazil, the C.I.S., Turkey, Sudan and Egypt. These countries account for more than 73% of the world's production.[1] However, there will be changes in this allocation due to individual developments of the nations (see also Chapter 1). China has already become an importer of cotton, even though its production has passed that of the US in recent years. Uzbekistan and Turkmenistan will increase the area for cotton growing in order to provide resources for their growing domestic textile industry, but may later need part of the cotton area for food production. Pakistan will primarily increase its textile industry with only a small increase (if ever) in cotton growing. Turkey and Australia will increase production simply by increasing the amount of irrigation. India's development in cotton growing is dependent on improvements in yield and may decrease owing to increased food demands (Cotton, Inc. 2001).

Cotton belongs to the botanical family Malvaceae. A few species were developed in the so-called Old World with a low market share, but they have a much higher share in the New World (see Fig. 2.4). Grown as an annual plant, cotton develops in its natural cycle from seed to seedling to a plant with vegetative growth, and forms a beautifully colored blossom. After the fading of the blossom the plant's natural wind distribution mechanism, the capsule, develops. In the green capsule thousands of fibers grow, first in length and second in diameter. When the capsule is mature, it springs open and offers the lint to the wind for distribution and the start of a new cycle (see Fig. 2.5). The mature capsule is the state in which cotton is harvested in order to extract the fine fibers by ginning. Natural varieties are adapted to the climate and environment in such a way as to ensure reproduction. If the fibers are used for textile fabrics, other quality parameters than those selected by nature become prominent, as shown by Tobler (2001a):

> 'Cotton growing is commonly indicated to be the crop with the highest amount of agrochemical applications and a tremendous consumption of irrigation water. Such statements are often listed by environment protecting groups, indicating greatest global impacts. Unquestionably sustainable development of agriculture is of global concern, and its importance for agriculture may not be underestimated. Even if one might assume that

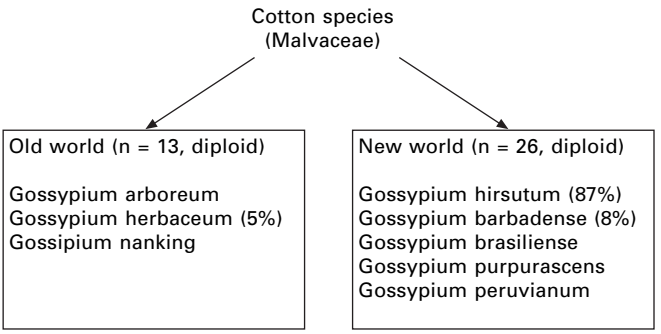
[1] Actual information can be taken from www.cotton.org and the Bremen cotton exchange publications.

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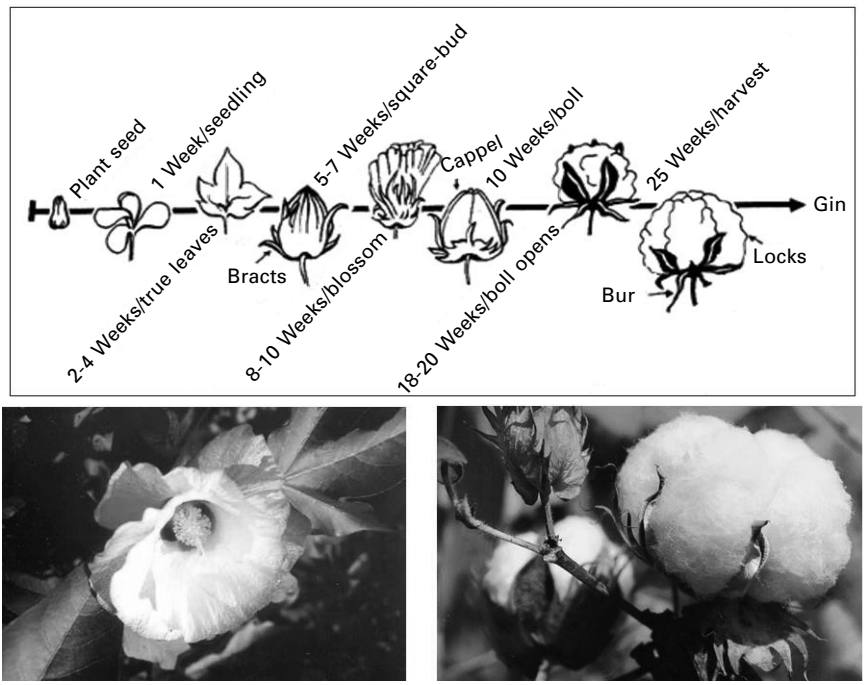
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2.3 Areas for cotton growing. The climate within 30° north and south of the equator is best suited for cotton plants (source: Bremer Baumwollboerse).



2.4 Cotton species in different growing areas of the world. The number of chromosomes of the New World's species has doubled.



2.5 Development and growth of a cotton plant from seed to boll (source: Alaca Company, 2001).

farmers knew best practices for a sustainable agriculture, political and economical conditions as well as new developments in industry make it difficult to find appropriate solutions for a sustainable agriculture.

Based on the commitments in 1992 for a local Agenda 21, many nations have developed their own indicator systems for environment and sustainability, according to the UNO Commission for Sustainable

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Development (BFS and BUWAL 1999). Knowledge of national indicators is helpful to develop a national environmental policy and guidelines for practices, particularly for agriculture (Rossier and Gaillard 2001). However, such indicators are based on specific national conditions like structure of the agricultural sector, economics, topography, climate and many others.

Encouraged by the WTO, the OECD is developing global environmental indicators in order to provide a global perspective for agriculture. For establishing OECD indicators in agriculture many data have to be collected on national levels, mainly based on statistics. For cotton growing national statistics on yield are available (USDA 2001), while information on costs and growing practices is not available in many nations. This process, launched by the OECD, involves researchers from many countries and will allow mutual learning especially for global crops like cotton. Consequently impacts of growing conditions will become transparent. Such agreements might contribute to a deeper understanding and acceptance of regional goals for sustainability. The process of establishing international indicators will support nations to develop or adjust their own national or regional guidelines. Unfortunately the USA, owning the largest cotton growing area, does not participate in this process, although they are an OECD member. Although the USDA defined some general guidelines for sustainable agriculture, there are no such guidelines for different growing regions and agricultural practices.'

The cotton growing season starts after the last frosts in spring. Already in winter organic matter and fertilizer are worked into the soil to provide the plant with sufficient nitrogen, phosphate and potassium. Tillage includes bedding and furrowing to prepare the soil for the seeds. There are different concepts for furrow construction in bedding, often in combination with specialized machinery (Abaye *et al*. 1996, CTIC a and b). At this stage the moisture content of the soil has to be preserved carefully, which influences the tillage activities (Pepper 2002). Poor practice will show up in inferior crop growth. Farmers particularly seek high-yielding varieties for economic reasons and follow agricultural regimes that maximize yield. They choose specific bedding practices (rowing), best suited for the available irrigation type and optimization between natural prevention of weeds (through dense planting) and enough area for growth (photosynthesis) as shown in Table 2.2.

Depending on the climate, a short-maturing variety has to be planted in order to achieve a mature crop before the first frost. There are varieties producing high quality also in short growth periods if the number of days with the required degree of heat is achieved or exceeded.

Besides fertilizer, many pesticides, insecticides and fungicides are applied to prevent losses in large monocultures. During the growing season

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Table 2.2 Preparation and cultivation for cotton growing in the Texas High Plains

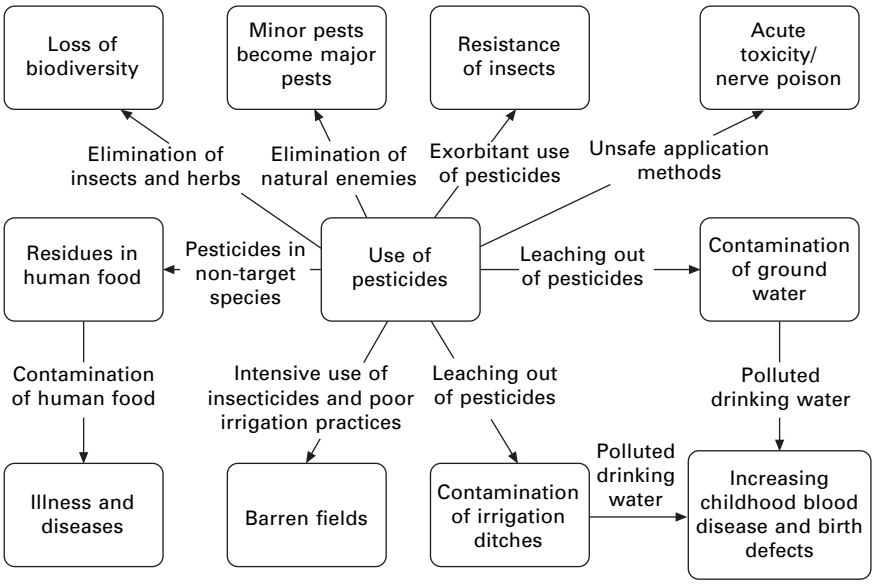
Crop rotation	Sometimes: soy, corn, cereals Rarely: sunflowers, alfalfa, vegetables
Soil preparation (sandy soil)	Add organic matter Bedding, furrowing Moistening
Disease control	Vaccinate against fungi, bacteria, nematodes
Growth/yield (fertilizer)	Addition of organic matter Addition of nitrogen Addition of phosphate Little potassium
Pest control	Boll weevil, aphids, bollworm, tobacco budworm
Weed control	Weeding, herbicides, transgenic variety
Irrigation (24 inches)	Early growth period: 0.1 inches/day Blossom: 0.35 inches/day Capsule: little irrigation needed

Source: ITC (2001).

considerable amounts of insecticides and herbicides are applied to prevent excessive feeding of pests and to allow the growth of a good quality of bolls (macroscopic view) and highest yields. However, treatment with pesticides, particularly if carried out in an inappropriate manner, may result in acute occupational health problems besides long-term effects on the population and on the ecosystem in the area, which are not desired (see Fig. 2.6). Some soils get salty and need chalk treatment; this does not concern Texas but it does affect the eastern USA, namely North Carolina, as evidenced by visits to the crop regions in 1976, 1979, 2001 and 2002. Even before seeding, herbicides are applied and, where necessary, the soil is irrigated. Irrigation is continued during the early growing period, when 0.1 inches a day are required, and especially during the blossom period with a demand of 0.35 inches a day. In the later growing season water is no longer so essential. As the plant grows it becomes more or less resistant to wind that might bend or crack it. When the plant is maturing, strong winds can destroy the structure of a boll. The choice of a variety with strong stems and/or an appropriate row system prevents most damage. Most of the cotton grown worldwide is picked by hand, regardless of the topography. Figures 2.7 and 2.8 show how small fields in India and in Greece are harvested. Only the USA, Australia and Israel have developed machinery for harvesting.

Harvesting by machine is prepared by the application of a maturing agent, accelerating maturation of the immature bolls of the upper part of the plant. This will allow a field to be harvested by a single mechanical harvest with machinery (Fig. 2.9) instead of two or three harvests by handpicking, where

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2.6 Potential negative impacts on the environment and people, caused by the application of pesticides (source: Klingler and Zaech 2005).

only mature bolls are collected (see Fig. 2.7) (Loew 2003). The application of a harvesting aid (defoliant) two weeks before harvest forces the plants to droop before the frost. The artificial maturation and defoliation allows growers to start harvesting earlier in the year and to use harvest equipment efficiently during a certain period, from September until December (Brassel 1999). Additionally the harvest technology, picker or stripper machinery, has to be adapted to the cotton boll type. Practically all the cotton is harvested by machine, either with a spindle picker or with stripper harvesters (Munro 1987). The spindle picker works with a number of rotating spindles which tangle with the seed cotton in the open bolls, pulling it away from the husk. This type of machine is used for all good quality cotton. The cotton stripper is a non-selective harvester that removes not only the well-opened bolls but also the cracked and unopened bolls along with the burrs and other foreign matter (Williford *et al.* 1994). The plant is literally brushed off and only the stem and some branches remain on the field. The only advantage of the manual operation is better access to the cotton bolls and a reduced trash content in processing.

Handpicking is the gentlest way of harvesting, and is still done in most cotton-growing countries. After slavery was abolished, the USA established a work force, the so-called sharecroppers, bound by contracts to the farm. By this the owner could count on workers during the harvest season when

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2.7 Cotton growing in small plots with manual harvesting (India).

the workforce market would become narrow. Although farmers built towns and schools for sharecroppers, their living was close to slavery, a fact the administration aimed to ban by different Acts. Newly developed cotton regions therefore set early on automated agriculture with the latest developments in harvest machinery (Rivoli 2006). Figure 2.10 gives a process-oriented analysis of cotton growing on the basis of the main indicators. As the market demand increased, large areas were cultivated with cotton, often consuming tremendous amounts of irrigation water (e.g. around the Aral Sea). Nations with large populations are often confronted with the question whether to cultivate cotton for exports or food for the domestic population. Often crop rotation is considered to be uneconomic in the short term. Governments of

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2.8 Cotton growing in Greece. No specific machinery for cotton growing is applied.



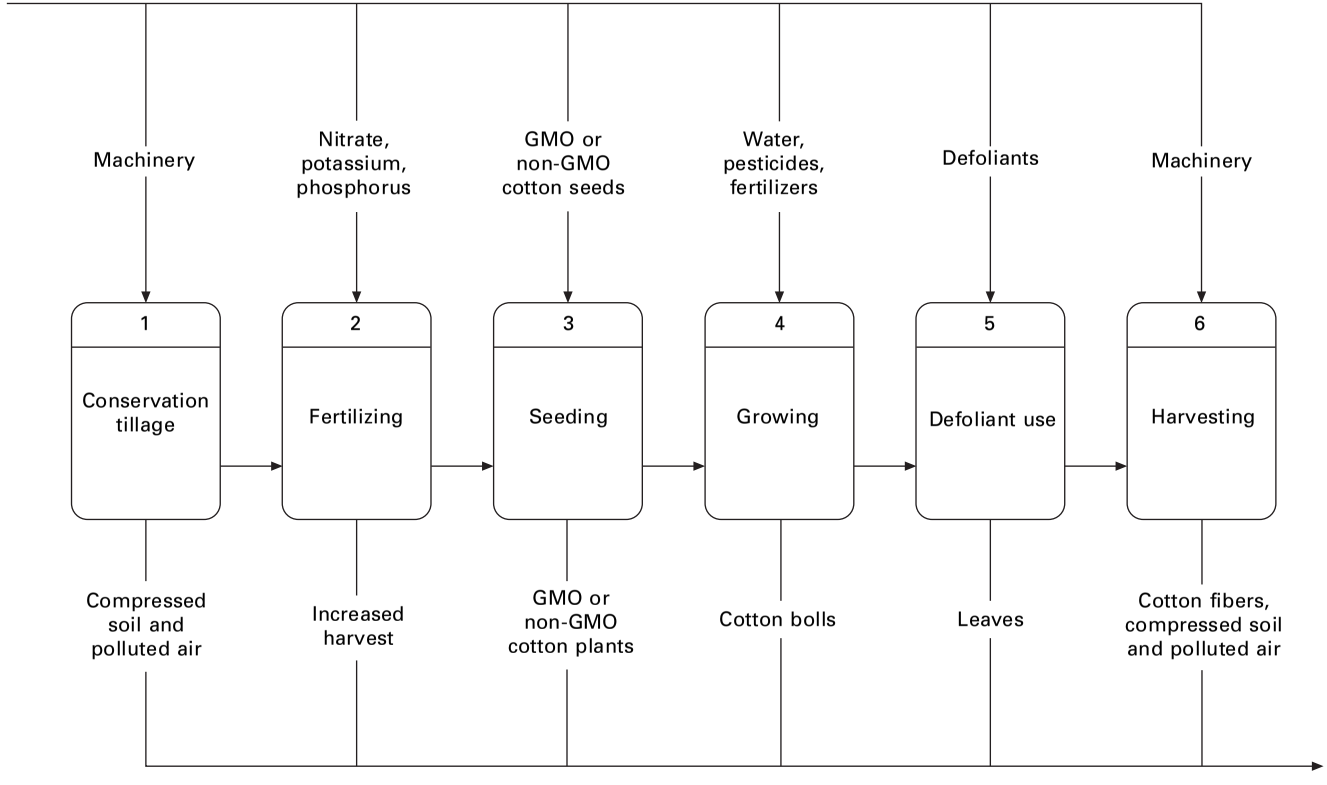
2.9 Harvesting machinery for stripper cotton in the Texas High Plains.

industrialized nations like the USA and Europe pay high subsidies to cotton growing (Misra 2003, Koroneos 2003). Such practices were to be phased out under the WTO in 2005 (see Chapter 5).

Organically grown cotton today represents a niche: less than 1% of the

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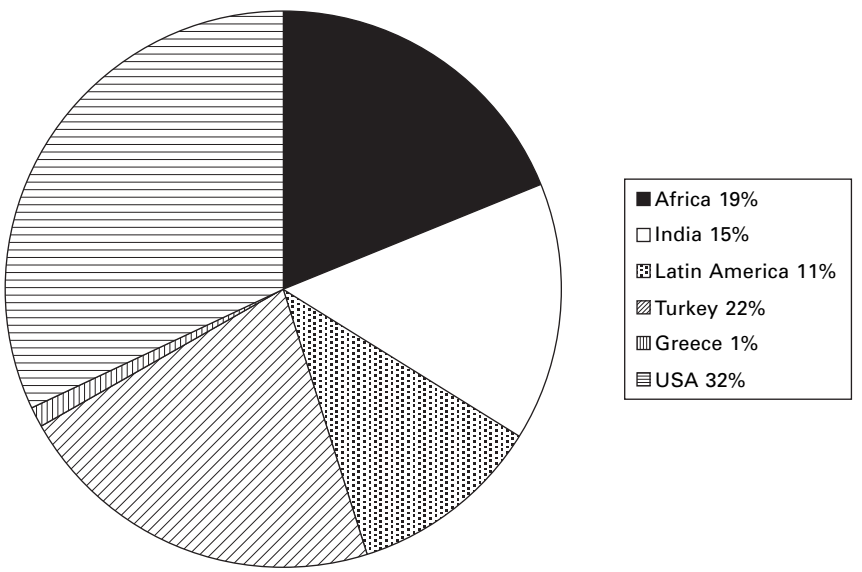
2.10 The main desired impacts on cotton growing and undesired impacts on the environment. Most cotton seed is treated with fungicides. For optimized moisture content of the soil, irrigation is applied. The defoliant replaces natural frost and an application of maturing agent is necessary for harvest by machinery.

annual yield is certified organic cotton with low acceptance on the market due to economic considerations (Gallaway 1994). Since it requires a lot of manual labor, developing countries are in favor of such agricultural practices for economic reasons. But today in nations with highly industrialized agriculture like the USA, the largest quantities of organic cotton are grown (see Fig. 2.11).

In all US agricultural regions where cotton is grown, also other crops are present, even if to a much lower percentage. The second important pillar of agriculture, livestock husbandry, is combined with crop growing. Consequently the focus will lie in sustainable development of agriculture as a whole. Such tendencies could be found in California[2] but not in Texas (Spaar 1997), although there is considerable organic cotton grown.[3] Our research was therefore focused on Texas and is discussed against a global background.

2.2.2 Four case studies

The USA, these days the greatest cotton growing area with four main regions, was chosen for the investigations primarily due to the availability of data.



2.11 Share of organic cotton worldwide. The total cotton production in 2003 was 90 million bales. Organic cotton represents only 0.5% of the world production (source: Marquardt 2000a).

[2] http://www.sarep.ucdavis.edu/concept.htm
[3] http://www.sustainablecotton.org/NEWS007/news007trends.html

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In a first study, differences between two major growing regions, California's San Joaquin Valley and the Texas High Plains (see Fig. 2.12 and Table 2.3), were studied (Spaar, 1997).

One of the biggest growing areas for cotton lies in Texas with enormous flat fields over hundreds of miles (see Fig. 2.13). Bowman and Keeling (1997) provided annual recommendations for cotton growing concerning application of agrochemicals and tillage, and Clark *et al*. (1998) evaluated the performance of the cotton production. However, studies on the environmental balance (Spaar 1997) in the Texas High Plains showed an unsustainable consumption of irrigation water. Although statistical and economical information on water consumption had been available for a long period (Ethridge *et al*. 1977), no political decision had been taken.

Case study A: A comparison – California and Texas

In the US, the beltwide cotton production in 1994 was 9072 million pounds on 12.3 million acres. The yields per acre increased steadily during the twentieth century due to increased chemical inputs and improved cotton varieties. California with its fertile soils, long growing season and constantly available irrigation water produces, with an average of 1178 pounds per acre, the highest yields per acre in the US. Texas, with its short growing season in the High Plains and the limited water, produces an average of 360 pounds per acre. The high yields per acre let California farmers use 0.01 pounds of chemicals to produce one pound of lint, whereas Texas farmers use half that amount. In California an average of 3.0–3.3 feet of irrigation water is applied to the cotton fields. In Texas cotton is produced with an average of 2 feet per acre. Per pound of lint, California uses 0.0028 and Texas 0.0044 cubic feet of irrigation water.

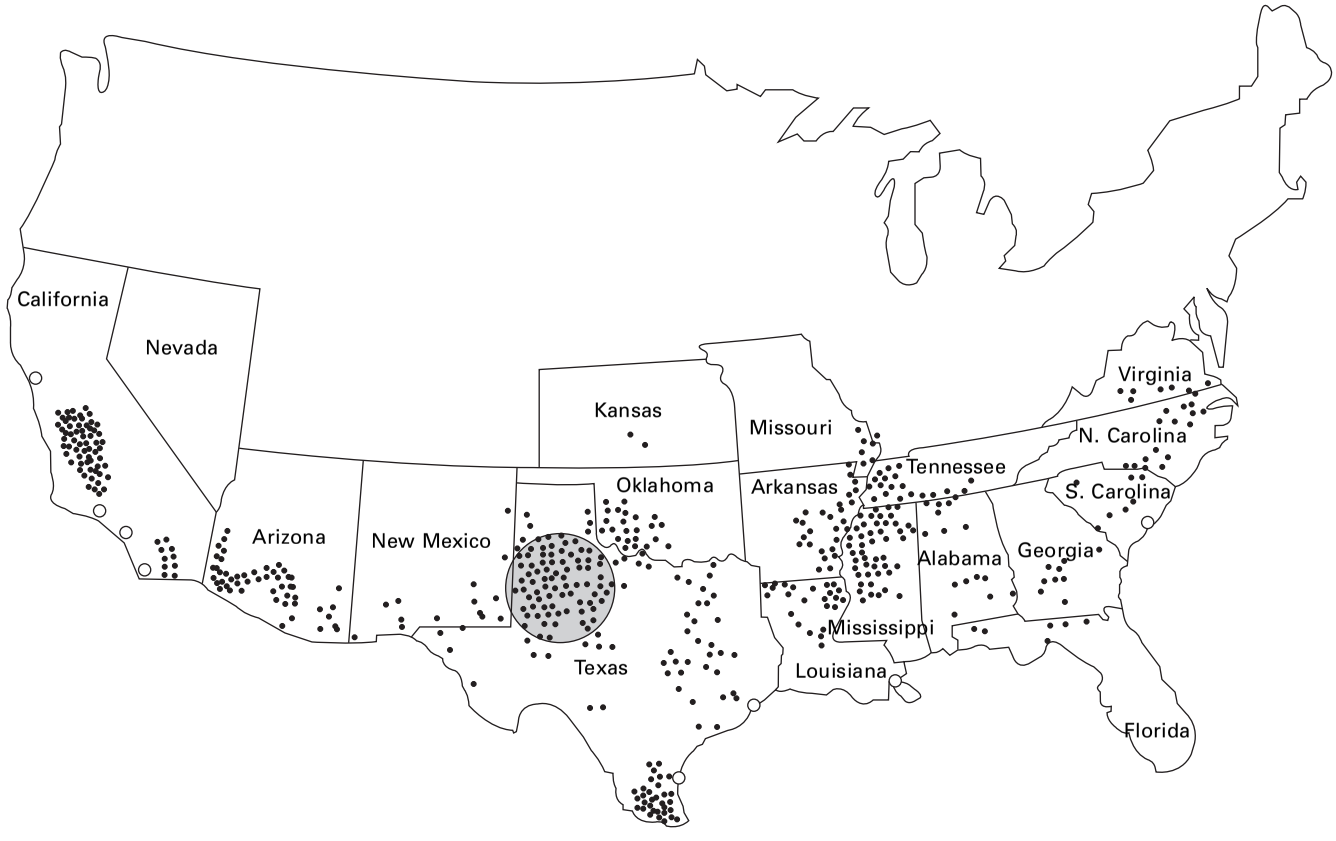
There are different methods of irrigating cotton fields, such as flood, furrow, surge, sprinkler and center-pivot irrigation systems. While some systems lose up to 50% of the applied water through evaporation, others may work with an efficiency of over 90%.

California has a very efficient surface and groundwater supply system. In drought years more water is pumped from the water basins than is recharged, but the water basins are recharged in wet years. Ninety percent of California cotton is irrigated by flood or furrow irrigation. Although California farmers have a high input of irrigation water and use inefficient irrigation methods, the water management must be considered sustainable.

The only available irrigation water for High Plains cotton farmers is provided by the High Plains aquifer system. Ever since the beginning of cotton production in the Plains the water table has declined. The increasing costs of pumping water and the unavailability of water forced the High Plains cotton farmers to invest in improved irrigation systems and to farm

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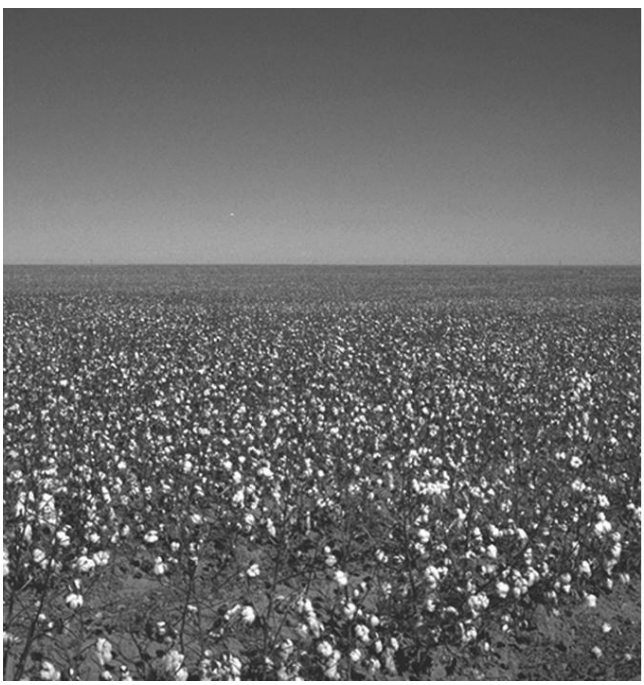


2.12 The Texas High Plains represent the largest of four areas for cotton growing in the USA.

Table 2.3 Characteristics of the Texas High Plains

- Semi-desert climate with variations from north to south (rainfall, temperature)
- Years with few rains (for dry land cotton) and heavy rains[1]
- Soil erosion by winds
- Poor organic matter
- Highly developed, industrial production system[2]
- Relatively poor long-term experience of the ecosystem
- Period of 'maximum input for maximum output'
- Invasions of pests (due to monocultures)[3]
- Soil compaction by tillage machinery
- Limited number of varieties (including GMO)[4]

[1] Personal communication, Don Ethridge, TTU, Lubbock, TX, 1999.
[2] Visit extension lab, TTU, Lubbock, TX, 2000.
[3] Personal communication, Dan Krieg and R. Bowman, TTU, Lubbock, TX, 1999.
[4] Personal communication, Jane Dever, Monsanto and John Gallaway, TTU, Lubbock, TX, 1999.



2.13 A cotton field in the Texas High Plains before harvest time.

about 1.4 million acres of cotton with only precipitation water. A computer model shows that the water table will continue to decline in the future. Water management has to have first priority in High Plains cotton fields to provide the area with sustainable development.

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Texas cotton farmers applied a total of 12.5 million pounds of chemicals to their 5.4 million acres of cotton in 1994. Texas farmers produce cotton with probably the lowest chemical input throughout the belt. The chemical inputs could still be reduced with alternative production methods.

California farmers used a total of over 15 million pounds of active ingredient in their 1.2 million acres of cotton. Not only the input rate but also the range of different chemicals used is different from Texas applications. The excessive use of chemicals in California could be drastically reduced with alternative production methods.

Integrated pest management (IPM) is an economical and ecological approach to managing pests by combining biological, cultural and chemical tools. Over 60% of Texas cotton farmers are considered IPM producers by the TDA. IPM in Texas is only an educational program by the Texas Department of Agriculture (TDA). There is no certification program for integrated production in the US. The definition of an IPM producer by the TDA could meet Swiss 'Integrierte Produktion' standards with some restrictions.

Only about 17,000 acres (or one past per million) of US cotton is produced organically. Federal and state regulations regulate all organic commodities in the US. Today, organic cotton is certified by private certification agencies in California and by the TDA in Texas. Any certified organic cotton of the US would meet Swiss 'Bio' standards already. The quality of organic cotton shows very little difference from that of conventionally produced cotton.

Cultivation costs are $491 per acre for a conventional producer and $453 for a user of beneficial insects because of the lower costs of the application of beneficials compared to chemicals. An organic producer has cultivation costs of $484 per acre due to the higher labor and assessment costs. While a conventional farmer produces his cotton for 70 cents per pound of lint, a beneficial user is able to produce his cotton for 67 cents per pound. The organic farmer, due to his additional costs and the lower lint return, produces his cotton for 94 cents per pound. (Spaar 1997).

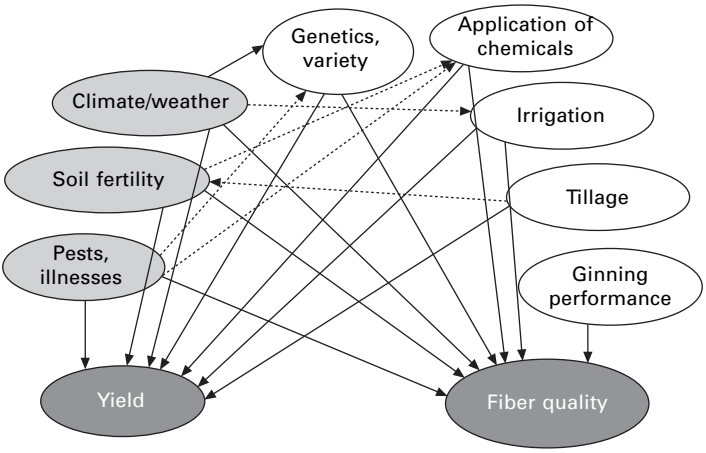
In the late 1990s it became evident that after a long period of increase, yields began to decrease. Moreover, spinners complained of the poor quality of the cotton fiber: too rough, too weak and too short, sometimes even immature fibers (for cotton processing see Cotton, Inc./TTU Lubbock 2001).

The situation for the US cotton grower can roughly be summarized by the factors given in Fig. 2.14. The grower has to make decisions in order to stabilize yield and improve fiber quality.

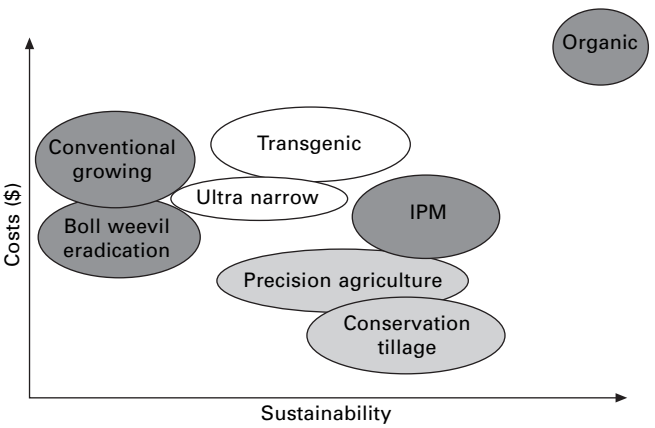
Case study B: Agricultural systems and practices

In a portfolio of costs and sustainability the most common practices of cotton growing were evaluated (Fig. 2.15). 'Integrated pest management'

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2.14 Parameters influencing yield and fiber quality. Some parameters are set by the environment (grey); others rely on decisions taken by the farmers. They all have direct (solid lines) and indirect (dotted lines) impacts.



2.15 Portfolio of the cotton production systems in the Texas High Plains with relation between cost and sustainability.

(IPM) and 'conservation tillage' as compared to 'organic' were analyzed more specifically in terms of sustainability (Hauser 2000).

The most precise definition in agriculture is 'organic'. Its primary goal is to 'optimize the health and productivity of interdependent communities of soil life, plants, animals and people' (Organic Trade Association, OTA). Organic agricultural practices cannot ensure that products are completely free of residues. Specific methods are used to minimize pollution from air, soil and water.

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'Integrated pest management' is a strategy that focuses on long-term prevention or suppression of pest problems with minimum impact on human health, the environment, and non-target organisms. Practices to achieve this goal are application of less harmful pesticides, biological control, adaptation of agricultural practices to avoid pests, and changes of habitats for pests (Flint *et al*. 1991).

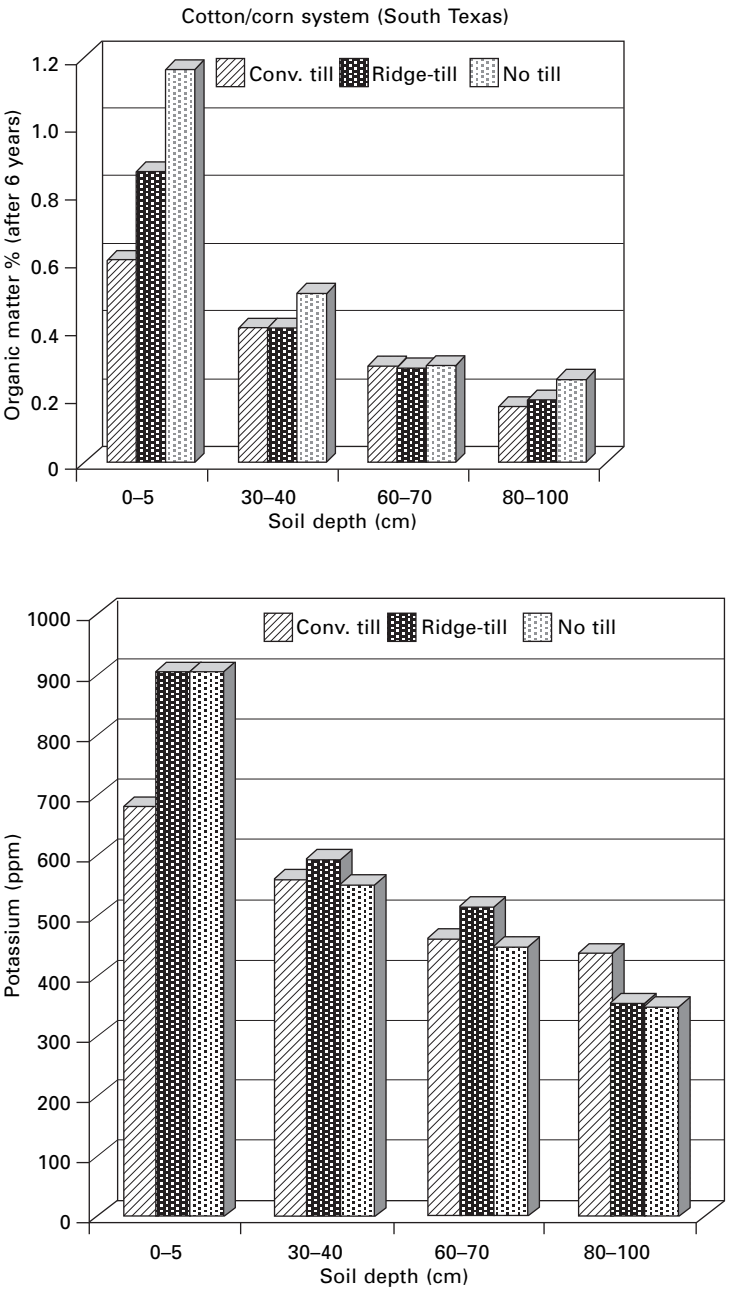
Conservation tillage production practices leave most of the previous crop residue (from harvest or winter cover crop) on the soil surface to provide mulch for the soil, increase water infiltration rates into the soil, and decrease wind and water erosion compared to conventional methods of seedbed preparation. Where soil erosion by wind is of primary concern, conservation tillage is defined as any system that maintains at least 1000 pounds per acre of flat, small-grain residue equivalent on the surface throughout the critical wind erosion period. Several conservation tillage methods are practiced, such as non-till, ridge-till, etc. (see Fig. 2.16) (Smart and Bradford 1999b). Improvements in the organic matter content of the soil as well as of potassium were found, but not for other minerals.

The results, elaborated on the basis of indicators, show an estimation of different scenarios in cultivation, based on statistical information and the given conditions of the Texas High Plains. The IPM scenario (Fig. 2.17) shows quite good results only for the indicators biodiversity and herbicides. All other indicators are hardly influenced positively. 'Organic', considered as the highest ecological standard, achieves best values for the indicators defoliants, fertilizers, fungicides, insecticides and herbicides. However, in 'conservation tillage' relevant environmental indicators like energy conservation, soil moisture, soil compaction and soil erosion achieve higher values than in the other scenarios. A combination of the 'organic' and 'conservation tillage' scenarios is shown in Fig. 2.18.

IPM, although highly accepted (because of economic benefits) but not so frequently used in Texas, did not prove to have a major impact on sustainable development, even if insecticides are reduced and biodiversity is enhanced. On the other hand the ecologically most restrictive production system, 'certified organic', was not superior in all parameters, mainly due to more general requirements that do not meet the specific situation of the Texas High Plains. The best ecological solution would be a combination of 'organic' and 'conservation tillage' of rain-grown cotton (Matocha and Keeling 1998). However, 'organic' requires a high amount of mechanical and manual work and therefore cannot compete with the industrial production system of the USA because of prices. No machinery is available for organic production; equipment has to be developed by farmers (Jack Minter, organic farmer in Texas). Considering the growing demand (Tobler 1999), however, more organic cotton could be produced worldwide.

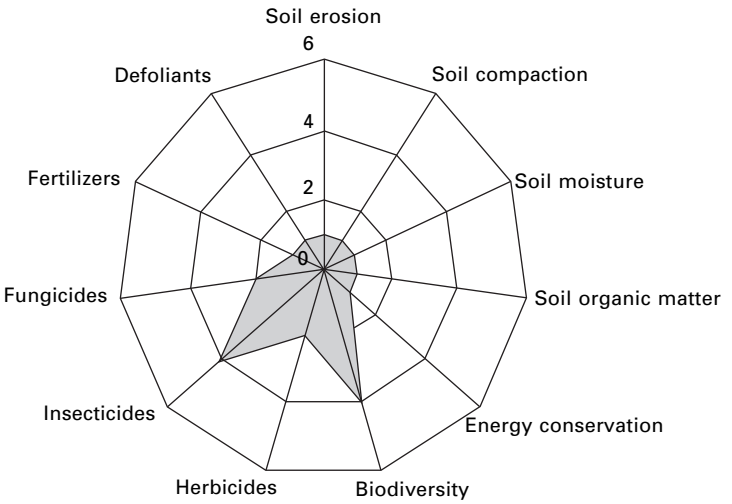
Improvements should also be made in promoting 'conservation tillage'

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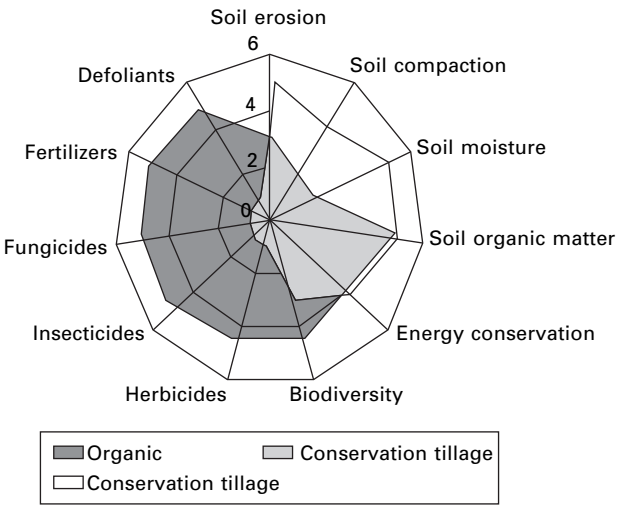


2.16 Impact of conventional till, ridge-till and no tillage on the mineral cycle in the soil in a six-year experiment. Mainly the surface layer accumulates organic matter and potassium. No differences were found for Na, Mg and Ca (source: Smart and Bradford 1999b).

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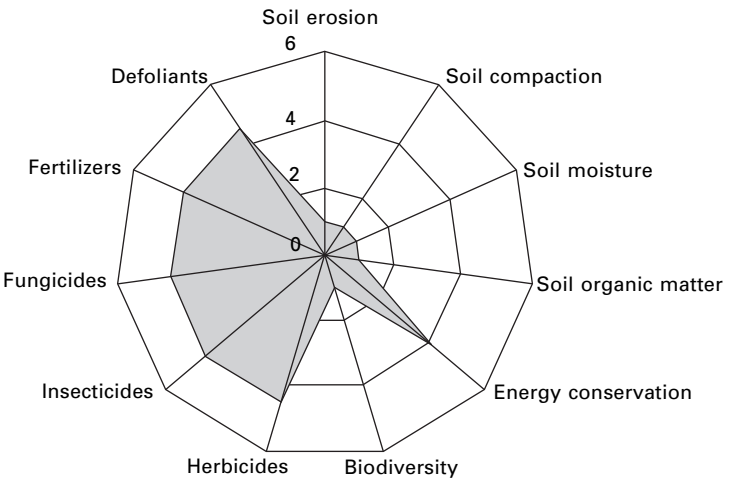
2.17 Integrated pest management (IPM) as a spider diagram. High values stand for ecologically beneficial values. IPM shows ecological benefits in the application of insecticides and herbicides.



2.18 A combination of the organic and conservation tillage scenarios as a spider diagram. By application of these combined practices best results can be achieved.

and IPM. An interesting solution for highly industrialized countries will be 'precision farming' (Fig. 2.19), an information- and technology-based agricultural system that identifies, analyzes and manages site spatial and temporal variability within fields for optimum profitability, sustainability

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2.19 'Precision farming' as a spider diagram. High values stand for ecologically beneficial values. This practice is mainly focused on optimized input of agrochemicals.

Integrated Cotton Ecosystem Management Model (ICEMM)

Parameters
- Weather: temperature, rain, radiation, wind
- Soil fertility: nitrogen, ammonia, organic matter
- Soil properties: density, water permeability, water conductivity, water retention
- Cultivation: tillage, planting space, planting time, application of water and chemicals

Simulation
- Uptake and distribution of water and nitrogen
- Transformation of organic matter and ammonia
- Root growth as replay on chemical and physical impedance
- C-assimilation and distribution to the organs
- Starting point and growth of organs

Output data
- Moisture content of soil
- N-level
- Plant altitude, knots, area
- Green and immature bolls
- N-, water- and carbon hydrogen-stress

2.20 'Precision farming' based on the integrated cotton ecosystem management model (ICEMM). Relevant parameters are collected and the plant metabolism is simulated. The output data are used for decisions in agricultural practice for a desired quality (source: Ribera and Landivar 1999).

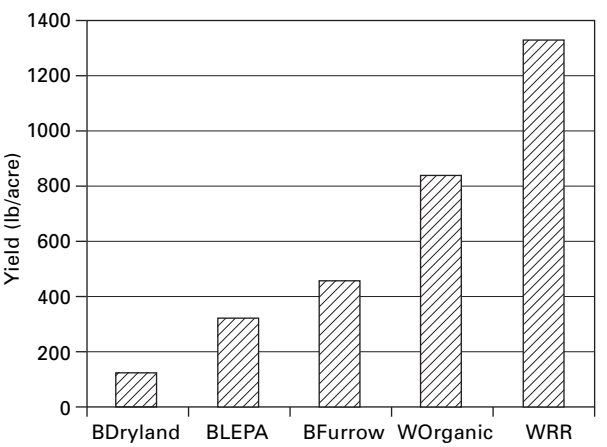
and protection of the environment (Fig. 2.20) (Johnson *et al.* 1998, Tobler and Schaerer 2002). Raper and Reeves (1998) report successful applications of the system in Tennessee, whereas in the Lubbock region the economic benefits were considered to be minor (Misra 2003).

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Case study C: Irrigation and growing of the variety H26

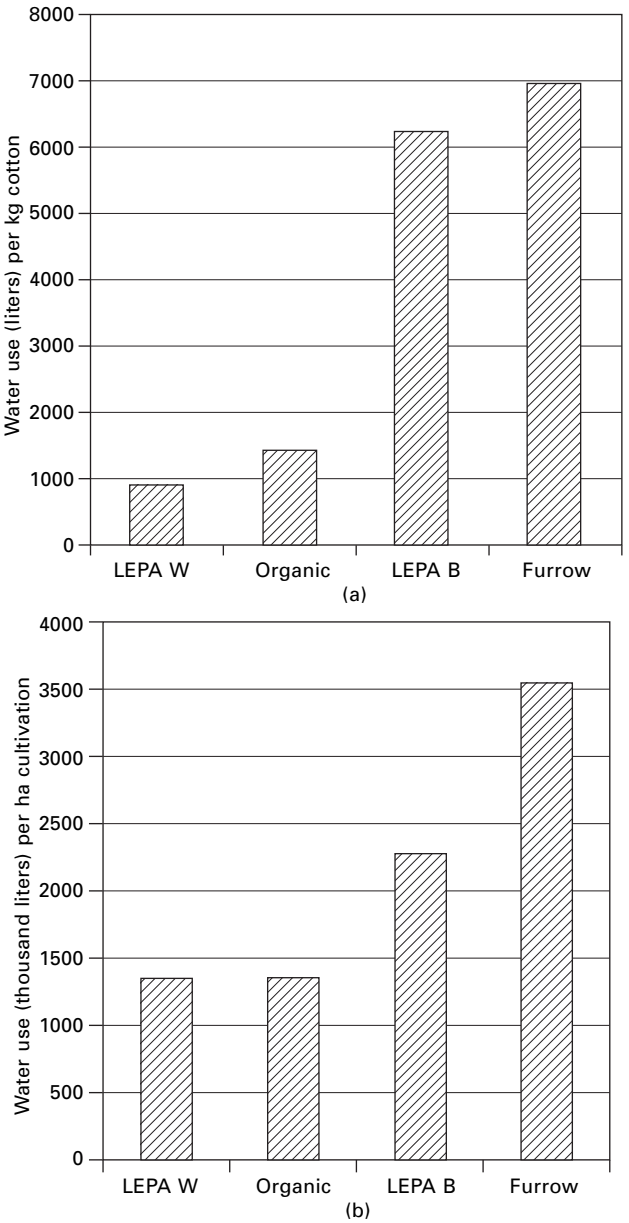
In the investigated growing scenarios two farmers worked with the same variety but different irrigation systems. Farmer B cultivated the systems 'BDryland', 'BLEPA' and 'BFurrow' as well as the Dryland system, while 'WOrganic' and 'WRR' were cultivated by farmer W. A first interesting finding was the differences in yield achieved by the two farmers (see Fig. 2.21). This clearly shows that the practice and experience of the individual farmer has a greater influence on the yield than irrigation systems. The low yield of BDryland can easily be explained by the very dry season of 2001. But the differences between the three LEPA systems 'BLEPA', 'WOrganic' and 'WWR', whereby the first is a conventional cotton, the second an organic cotton and the third a GMO cotton, can only be explained by the different agricultural practices of the two farmers. At least BLEPA and WOrganic should show a comparable yield. Regarding the water input per hectare applied in the different systems (see Fig. 2.22(b)), there is evidence that farmer W has practiced inferior water management, i.e. water supply appropriate to the requirements of the plants. The water consumption may not be considered without reference to the yield (Fig. 2.22(a)) and consequently leads to different water consumption per kilogram of cotton (Tobler and Schaerer 2002). Further considerations of this case study concerning the relations between yield, costs and environmental impacts are given in Chapter 4.

Farmers in the USA have been seriously concerned about declining cotton yields for the last three years, fearing a loss in return on investment in their agricultural systems for cotton. Since the indicator for a prospering agricultural business in the USA, as in most businesses, is the net return over one year,



2.21 Yields of the five irrigation scenarios in the Texas High Plains: BDryland = rain-grown; BLEPA, WOrganic and WRR = LEPA system irrigated; BFurrow = furrow irrigated.

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2.22 Water consumption of the irrigated production systems (see Fig. 2.21) per kg and per ha.

there is a lack of long-term consideration for agriculture. This lack is very crucial because false development in the agricultural system can lead to possibly irreversible deterioration in soil quality. The development of goals

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is a very complex issue because both agricultural practices and environmental considerations in areas where cotton is grown may vary widely.

However, the farmers are even more concerned about decreasing HVI quality parameters like length and strength. The tendency towards decreasing yields and quality parameters, after a period of increase over 30 years until 1996, has been observed all over the USA as emphasized at the Beltwide Cotton Conference in 2000. Considering upland cotton in Texas, micronaire tending to higher values (premium 3.5–4.9) has been causing some difficulties for the spinning of fine yarns. Further more, average lengths of 33 mm and strengths of 28 cN/tex have been measured, whereas spinners would require a length of 35 mm and a strength of 31 cN/tex. Other imperfections like neps, immature fibers and short fiber content have a great impact on the spinning performance. However, these parameters are not expressed by the HVI and therefore have no influence on the pricing system.

Selection of varieties by farmers in the Texas High Plains (semi-arid climate) is driven by two main forces: the climatic conditions and the quality requirements. The requirements for cotton varieties in general and for a semi-arid climate are as follows.

- General requirements:
 - High yield
 - Resistance against illnesses
 - Long fibers (staple length)
 - Strong fibers (cN/tex)
 - Fine fibers (micronaire)
- Climatic requirements:
 - Early maturing (short season)
 - Stability of stems (wind exposed)
 - Dense boll packaging (wind exposed, dust)
- Seed requirements:
 - Dry stored seed (from mature, dry bolls) (only in a dry climate and not genetically modified species)
 - 17–26 kg seeds for an average yield of 525 kg/ha
 - 100,000–135,000 plants per ha.

Much experience is necessary to understand the relation between the growth steps of cotton and the specific requirements of minerals and water to get good staple length, high strength and fine, mature fibers.

As shown in Fig. 2.14, the choice of variety is determined by different factors. For a good net return, varieties with high yields are selected. However, climatic conditions as well as weather conditions have to be considered. Especially, maturing time has to be adjusted to the climate, as well as properties of plant physiology (e.g. C-assimilation under heat stress)

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and plant anatomy (e.g. wind-resistant stalks and bolls). The latter also determines the type of harvesting machinery of a region (picker or stripper). Further properties like resistance to illnesses are also genetically fixed. In recent years some genetically engineered organisms have been developed and widely applied (up to 80% in Texas).

However, fiber parameters like micronaire, length or strength are not of superior interest for the choice of the variety. Not all fiber parameters are determined by genetics, and even those that are will be influenced by many factors such as soil, climate and weather as well as cultivation and ginning practice. While length is mainly determined by genetics, heat, water stress and lack of potassium as well as ginning performance contribute to the parameter. On the other hand, declassification in micronaire, the measure for fineness of the fiber, is due to either immature fibers (low values) or high temperatures combined with water stress (high micronaire). The quality parameters of reflectance (Rd) and yellowness (+b) depend highly on environmental influences such as growing of fungi combined with high moisture in the field and in the module, early frost, and heat in the gin. These are only a few examples of interactions between fiber parameters and cultivation practice (Tobler 2001a).

Case study D: Organic cotton

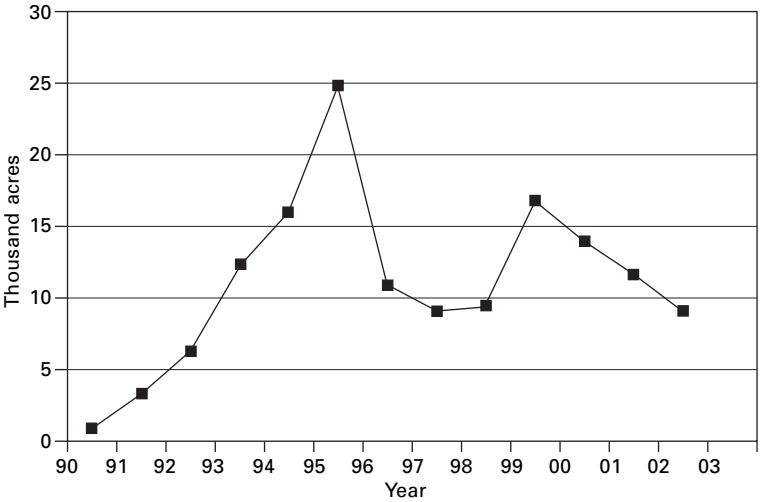
Despite the technological orientation of US cotton cultivation, a considerable amount of organic cotton is grown in the USA (see Fig. 2.23) on about 14 farms. The US share is by far the largest, compared to the worldwide production (Fig. 2.24). Depending on market demands (fashion) and pest eradication programs in the USA which prevent certification, this amount varies from year to year. Klingler and Zaech (2005) analyzed organic cotton conditions in their ETH thesis.

'Organic' refers to the way of growing and processing agricultural products. Producing 'organic' goods stands for a commitment to a system of agriculture that aspires to 'a balance with nature, using methods and materials that are of low impact to the environment' (Marquardt, 2003).

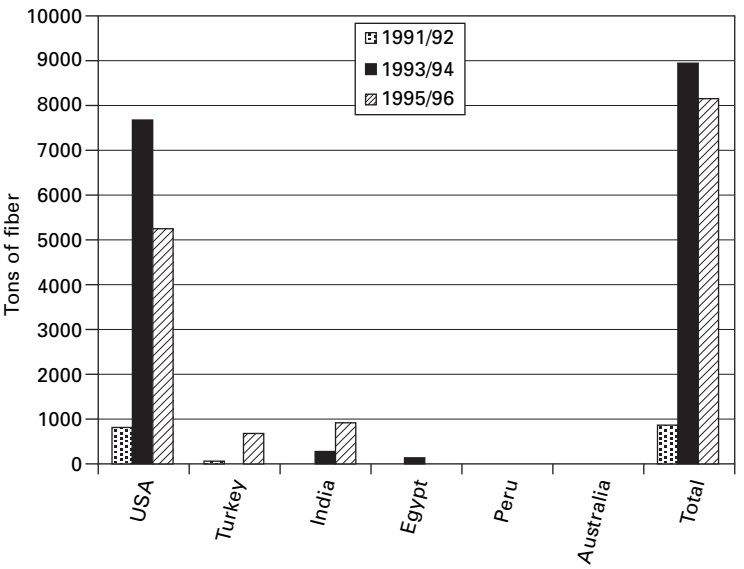
To summarize the problems brought up by conventionally grown cotton, it can be concluded that 'reduced soil fertility, salinization, a loss of biodiversity, water pollution, adverse changes in water balance, and pesticide-related problems including resistance' are the most important environmental and human health impacts (Myers 1999).

As cotton is susceptible to insect infestation and often grown as a mono-crop, large quantities of chemically produced pesticides and fertilizers are applied and cause therefore a subversion of natural nutrient cycling and natural pest control. Chemically produced pesticides and fertilizers can lead to various impacts which are diagrammed in Fig. 2.6.

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2.23 Estimates of US acreage planted with organic cotton (source: Marquardt, 2003).



2.24 Organic cotton production in the 1990s.

Cotton yield is also correlated to the amount of water applied, as most crops nowadays are irrigated. Often too much water is taken from ground or surface waters which runs lakes dry (e.g. the Aral Sea in Uzbekistan) or depletes phreatic waters. Evaporation of irrigation water from the soil surface often results in salinization and barren fields (Myers 1999).

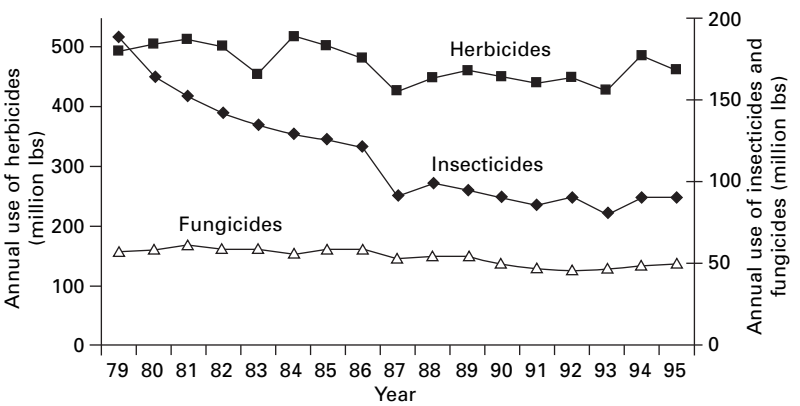
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Although genetically engineered cotton[4] was intended to be 'environmentally safe', there are several concerns about these plants (Myers 1999). Bt cotton is modified with a gene from the bacterium *Bacillus thuringiensis* and produces a toxin which kills insects. The two main concerns about Bt cotton are insect resistance and Bt gene flow to wild relatives.

Herbicide-tolerant cotton plants such as bromoxynil-tolerant cotton or glyphosate-tolerant (Roundup-Ready) cotton[5] have been genetically engineered to be resistant to a herbicide that would kill a normal cotton plant. As a result, the herbicide can be applied without killing the cotton plant itself. The main intention in developing this kind of engineered organism was to reduce herbicide use, but as yet there is no proof that herbicide use will decline.

The decreasing amounts of pesticide used (Fig 2.25) should not be interpreted as a decline, because the newly developed agents have become ever more effective in such a way that smaller amounts can be very toxic (Klingler and Zaech 2005).

Organic farming is a production system of ecological soil management that relies on building humus levels through crop rotations, recycling organic wastes, and applying balanced mineral adjustments. When necessary, this system uses mechanical, botanical or biological controls that have minimum adverse effects on health and the environment. Organic cotton is produced without the use of synthetic pesticides, synthetic fertilizers, synthetic defoliants and other synthetic chemicals (McKinnon 2000).



2.25 Development of applications of pesticides in the USA. Only insecticides show a reduction in use.

[4] GMO = genetically modified organism.

[5] Both herbicides are produced by multinational agrochemical companies (Rhone-Poulenc and Monsanto).

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According to the Organic Trade Association (OTA),[6] certified organic cotton is grown using methods and materials that have low impact on the environment. Organic production systems replenish and maintain soil fertility, reduce the use of toxic and persistent pesticides and fertilizers, and build a biologically diverse agriculture. Third-party certification organizations verify that organic producers use only methods and materials allowed in organic production.

2.2.3 Standards and requirements

National standards

The Organic Foods Production Act (OFPA), which is a title of the 1990 Farm Bill, intended to set national standards for the production and handling of foods and fibers labeled as organic. Therefore the National Organic Program (NOP) was set up, which was to establish these national standards. The USDA has been approving US organic standards in the National Organic Program.

Requirements for 'organic' in Texas

Production practices and materials are classified as 'permitted', 'prohibited' or 'regulated' by the USDA. Permitted and prohibited materials and practices apply statewide. Regulated materials and practices may vary from region to region. The department may approve the temporary use of regulated practices and/or materials upon demonstrated need.

According to McKinnon (2000), Coordinator of Organic Certification for the Texas Department of Agriculture, farmers need to demonstrate compliance with several key issues in order to become a certified organic producer. The following information on the requirements for Texas organic producers is modified from McKinnon (2000).

Land history

The department certifies crops as 'organic' only if harvest has occurred at least three years after the most recent use of a prohibited material. Producers of planted crops who have satisfied all requirements for certification except the passage of the required three-year period may market their crops under the Texas Department of Agriculture's 'Transitional – Organic Certification Pending' label.

[6] Organic Trade Association (OTA), Richmond, CA, http://www.ota.com

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Buffer zone requirements

Distinct, defined boundaries must exist between fields under organic management and other fields. This buffer zone must measure at least 25 feet. If the field is located next to a field in which a prohibited material is used, then an additional 25-feet buffer zone is required. Additional buffer zones may be imposed, depending on local conditions.

Documentation and record keeping

Producers must maintain a record-keeping system including records of all production practices, harvest dates, yields, and other data. There must be complete records of purchases, inventory and usage of materials including application dates, rates and so on.

Soil management

Soil amendments and fertilizers categorized as permitted or regulated may be utilized for supplemental sources of nitrogen, phosphorus, potassium, calcium, magnesium, management of soil pH and micronutrients. Crop nutrition management must be based on annual soil fertility analysis and/or plant tissue analysis. Soil condition must be improved primarily by increasing the organic matter content. This can be realized through crop rotation, cover cropping, manuring and composting. The new approach with a field cleaner in harvesting, leaving organic matter on the field (see Section 2.2.5), may be a contribution to good management. Soil conservation practices are required. This may include conservation tillage, terracing, benching and others. Also included are adequate use of cover crops, mulches and surface crop residues to enhance soil and water conservation.

Seed treatment

For organic cotton production, seeds must be used that have not been treated with any synthetic fungicides. Treated seeds may be used if untreated seeds are unavailable.

Weed management

Use of any synthetic herbicides is prohibited. Weed management of both annual and perennial weeds must be through extensive preventive weed management practices including crop rotation, cover cropping, mulching and others. Also, cultural practices such as mowing, grazing and shallow cultivation are allowed.

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Insect pest management

No synthetic insecticides may be used for organic production. Insect pest management should be based on integrated pest management principles including cultural practices such as planning production schedules, planting resistant varieties, planting dates, crop selection, rotation, trap cropping and intercropping. Producers may use other practices including pheromone traps, sticky traps, vacuuming and water jets, or other mechanical or physical controls. Also extensive use of beneficial organisms such as parasites, predators and pathogens is encouraged. Pheromones used in traps or for mating disruption are also allowed. Biological pesticides such as Bt (*Bacillus thuringiensis*), viruses and fungi are permitted. Minimal applications of permitted or regulated materials such as insecticidal soaps or natural vegetable oils are permitted pest controls. Use of botanical pesticides is a regulated pest control method and may be utilized only upon justification of need.

Disease management

Disease prevention is through consideration of planning production schedules, choosing crops, locating and sizing of planting, and deciding soil-management practices. Management practices such as planting resistant varieties, timing of planting to avoid cycles of pest emergence, intercropping, crop rotations, and avoidance of excessive fertilization can be useful in preventing disease problems. If justified and authorized by the department, a producer may use several copper- and sulfur-based fungicides.

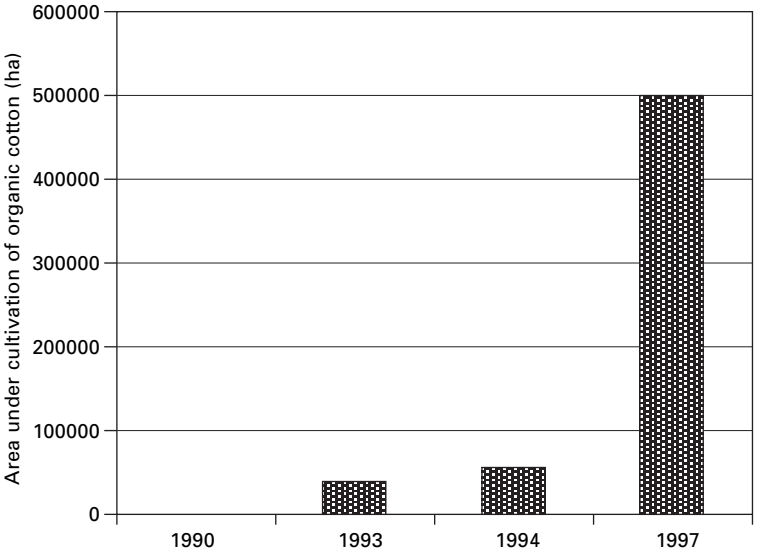
Defoliating

Conventional growth regulators and defoliants are not allowed in organic cotton production. Instead boll maturation and defoliation is accomplished by water and nutrient management and some regulated defoliants. Effective defoliation is still one of the major problems in producing organic cotton.

The source of the above information is Hauser (2000).

The production of organic cotton is highly dependent on national conditions. When in Egypt organic cotton was subsidized by the government, it increased its market share dramatically (Fig. 2.26). Such projects as the SEKEM farm are carried out in cooperation with international organic trade organizations. The promotion of cotton increased not only the production but also the domestic market, and for the women working in the fields a kindergarten was built. Thus ecology, economy and society all benefited: a good example of sustainable development.

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2.26 Growth of area under cultivation of organic cotton in Egypt.

2.2.4 Sustainable cotton growing in Texas

The cultivation system for cotton in the Texas High Plains is characterized by the following properties. Due to climatic conditions most of the cotton is irrigated. There are some years in which dryland cotton can be harvested; in other years not enough rain falls in the critical period. As was realized some 30 years ago, the aquifer from which the water for irrigation is taken decreases steadily. Water-saving technologies have been developed and are widely applied.

The cultivation systems applied in the Texas High Plains are determined by economic factors (Ethridge *et al*. 1977, Smith *et al*. 1996). Fiber quality is considered as a driving factor only as long as it affects pricing. Some economical farming practices also show an ecological benefit. The only pure ecological cultivation is 'organic'. 'Integrated pest management' and 'conservation tillage' both allow reduction of costs with the side-effects of reduction of pesticides or soil fertility and compaction. 'Precision agriculture' as a principle aims at optimizing fertilizer use using image analysis by satellite. 'Ultra narrow', bedding with narrow furrows, prevents the growth of weeds and soil erosion. By growing genetically modified organisms (GMOs), either tolerance of herbicides is achieved, or feeding of specific pests like boll weevil or boll worm is prevented. National programs for eradication are carried out by repeated spraying of specific pesticides over years.

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Examples of sustainable agriculture in the Texas High Plains (THP)

Experts and researchers in Texas have a deep understanding of the cotton production system (Supak and Metzer, undated). Research centers have experience in pest management (Smith *et al*. 1996) and conservation tillage (Bradow *et al*. 2000) over a period of some years, showing promising advantages for both economy and ecology. In practice, one harvest with a bad result may force the farmer to change his cultivation practices. However, practices should not be skipped without long-term experience.

Simulation programs for precision agriculture have been developed. However, there are no incentives so far from the national body (NSDA). The National Cotton Council is about to establish a system for sustainable cotton growing.[7] Even the support for existing organic production is very poor: the planned eradication program against the boll weevil will prevent organic production for years in the treated area.

Goals and requirements for sustainable agriculture

Long before the OECD defined the term sustainable development, it was practiced by foresters to allow the harvesting of trees without shortening the capital of the forest. Brundtland in Our Common Future asked for 'the same conditions for next generations to meet their needs'.

Sustainable cotton growing

Today most definitions require optimization of economic, ecological and social aspects within sustainability. One would think such a strategy could easily be applied to agronomy, but the inherent timeframe is different in agriculture and forestry. While crops can be harvested within the same year they were seeded, it takes decades to grow trees. Certainly this is the main reason for long-term economy in forestry and short-term economy in agronomy. Some countries in Europe such as Switzerland have developed strategies for sustainable agriculture. In the USA values are somewhat different from those in Europe and land is not a rare commodity. However, the indications of decreasing yields and fiber quality might favor goals for sustainable development. Sustainable development as an optimization of economy and ecology for the farmers will provide long-term sustainable agriculture and thereby support a society living from agriculture.

Sustainable development for cotton requires a holistic strategy, supported by government and policy as a framework. Otherwise the solutions will be individual, according to personal values, and in a marginal number of

[7] Personal communication, 2006.

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projects applied. A strategy should include goals and solutions as shown in Table 2.4.

The driving factor in the system is economy, the basis for the farmers. As long as cotton prices do not refer strictly to quality aspects, no significant change will be achieved. There is an urgent need to revise the HVI classification of cotton, especially the leave grade (see HVI quality parameters in Chapter 3). Promotion of other crops will help to change farmers' attitudes against crop rotation. All goals have to meet good and economic farm practice.

Farmers change their agricultural strategy based more on economic considerations than on long-term soil fertility (sustainability) (Hauser 2000). Improvements could be achieved by means of three main activities (see Table 2.4): selection of best practices (Indicator), regulations and incentives (Measures) as well as education for sustainability (Actors). The latter affords good economy and long-term oriented agriculture. Farmers generally do not adapt new production practices unless they are profitable.

Table 2.4 Goals, requirements and solutions for sustainable agriculture in the Texas High Plains

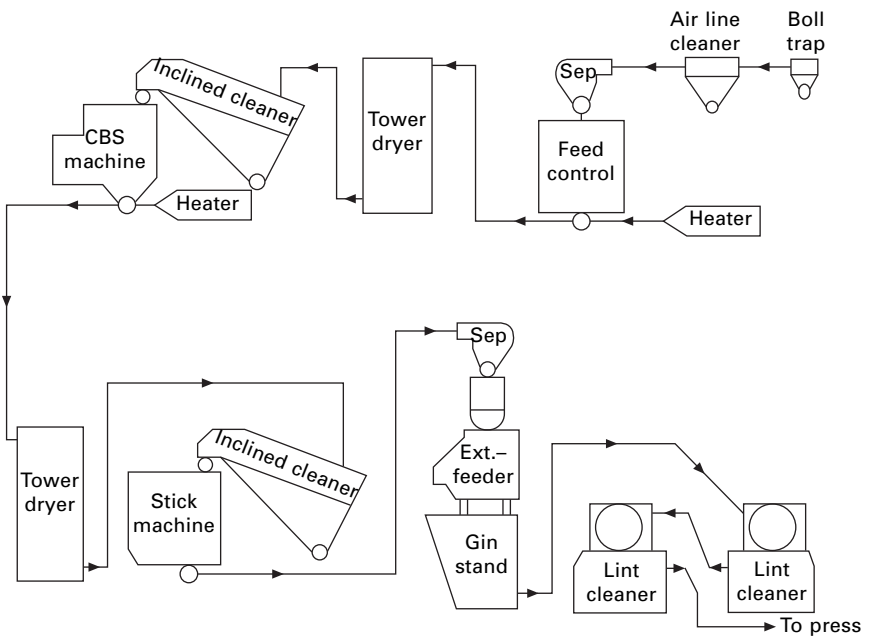
Aspect	Indicator	Measures	Actors
Water consumption	Efficiency in irrigation	Regulations for water use, incentives for dryland cotton	Economy
Pesticides	Precision agriculture, specific/organic pesticides, GMOs	IPM as standard, promotion of organic cotton	Instructions and consulting in best practices
Soil fertility	Crop rotation, conservation tillage	Promotion of alternative crops	Consulting
Biodiversity	Development of organic pesticides	Promotion of beneficial insects, enhancement of refugees	Information
Artificial fertilizer	Organic matter on field (field cleaner), IPM	Cooperation with livestock management	Economy and ecology
Soil erosion	Ultra narrow protection crop	Landscape protection against wind	Consulting
Soil compaction	Reduction of tillage, innovative machinery	Less heavy machinery	Instruction
Cotton varieties	Evaluation of new varieties	Broadening of genetic base	Recommendations
Fiber quality	Innovation in gin processing	Adjustment of cotton classification, incentives for good fibers	Economy
Economics	Adjustment of fiber quality	Introduction of new markets	Monitoring and consulting

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The existing cooperation between universities and applied cotton production[8] should be improved and focused on long-term studies. As long as breeding of new varieties remains with companies, short-term returns will be aimed at. Therefore universities also should cultivate rare cotton species and develop new varieties whereby the genetic base of cotton is broadened (Gallaway 1994).

2.2.5 Cotton ginning

Industrial ginning is carried out in huge halls, where material is transported in large tubes by air flow. The operations consist of several steps (schematically drawn in Fig. 2.27): first the seeds with the lint are removed from the cotton boll by separating barks, sticks and other residues of the plant as well as coarse foreign matter like stones from the field in a bur extractor. Second, in the gin stands the lint is removed from the seed by means of saws or rolls (see Fig. 2.28), where from the lint is transported to the third process, drying of the lint in drying towers with temperatures up to 200°C. The fourth step consists of a system of lint cleaners (one to three) to remove foreign matter



2.27 Schematic view of ginning processes with new CBS machinery for bur extraction. The second lint cleaner may be bypassed.

[8] Farmer meeting (visited in 1998 and 2002).

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2.28 Saw gin for separating fibers and seeds. The insert shows cotton flocks in movement (source: Simone Schaerer).

from the lint. Finally the lint is pressed in bales from which individually a sample for quality classification is gained (USDA 2001). Quality aspects of the fibers and ginning technology improvements are described in Chapter 3. A by-product of ginning is seed cotton which can be used for the next season's crop if the storage climate does not contain too much moisture. Genetically modified varieties are banned for crop production. The seed is used for seed oil production or livestock feeding.

One of the most important demands for action is for innovation in harvesting and ginning technology in order to prevent fibers from damage. Adjustment to spinning technology should be aimed at, in which a new partition of processes (harvesting–ginning–spinning) should not be excluded (Demuth 1993).

2.2.6 Bast fibers: flax, linen and hemp

Before cotton entered the global market, the most common textile fibers were flax, linen and hemp. Today their market share for apparel purposes is very small, as bast fibers like linen and hemp are today only grown in niche production. The impact of growing these fibers is much smaller than that of cotton, since there are no large areas in monoculture. Both bast fibers

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have very modest climate requirements and can easily be grown with crop rotation. *Cannabis sativa* (hemp) is grown in moderate climates without application of pesticides and agrochemicals. It even contributes to enhancing soil fertility and biodiversity (see Table 2.5) as shown by Leupin (1999) and Maag (2000).

Within 3 months the plant grows up to 4 meters. Yield is about 10–20 t/ha, from which 2 to 5 tons of raw fiber can be extracted. The by-product of fiber production, the shives, can be applied in the paper industry, for insulation, lagging or packaging material, or simply as stable straw. Today cannabis plants are often illegally grown for drugs with a high content of the active substance tetra-hydro-cannabin (THC). For fiber production, varieties with specific properties, including a low THC content of 2–3%, are required. One big advantage in growing hemp is the almost negligible use of pesticides. However, if larger areas were cultivated with this crop, potential pests would have to be monitored carefully. On the other hand, economic aspects have to be considered carefully, as many industrialized nations subsidize growing of linen and hemp. A close cooperation between growing regions and the domestic industry allows the development of innovative products (Reiners 2004).

Hemp for fiber production can be harvested before the development of the blossom (Leupin 2004). First the stems are retted and/or debasted, secondly they are cut to the desired fiber length, and thirdly the material is degummed, whereby the lignin between the fibers is removed (see also Chapter 3). Several retting processes are practiced, whereby often a high contamination with organic degradation products in surface and possible groundwater must be assumed.

Table 2.5 Sustainability of hemp production in cooperation with domestic industry

Sustainability	Industry
• Renewable • Short distances • Extensive cultivation • No pesticides • Crop diversity • Crop rotation • Resource management • Environmentally friendly processing • Waste treatment • Biological degradation • CO_2 -neutral incineration • Recyclable • New Income	• Direct contact with grower • Technical properties – high temperature • Regulation – Water uptake • Potential for innovation

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2.2.7 Wool

Wool was the most common textile raw material over a long period of time. In the late Middle Ages its share was close to 80%, but it declined to 20% in 1900. Today only 5% of all apparel is made of wool. Different animal fibers have been used for woolen textiles ever since people have settled. Sheep wool still represents the largest resource. In sustainable livestock farming, care is taken to grow the domestic animals in a natural environment with appropriate food. It is difficult to graze a large feedstock of animals on a restricted area, as the grassland is overstressed due to excess use. Precious fibers like cashmere, angora and alpaca are grown with animals in herds in mountain regions. These animals are kept in a traditional way close to their own natural environment. But most of the economic benefit gained from these luxurious fibers is not with the producer. This represents an economic threat to the local population, living very close to nature. Their existence cannot be considered sustainable.

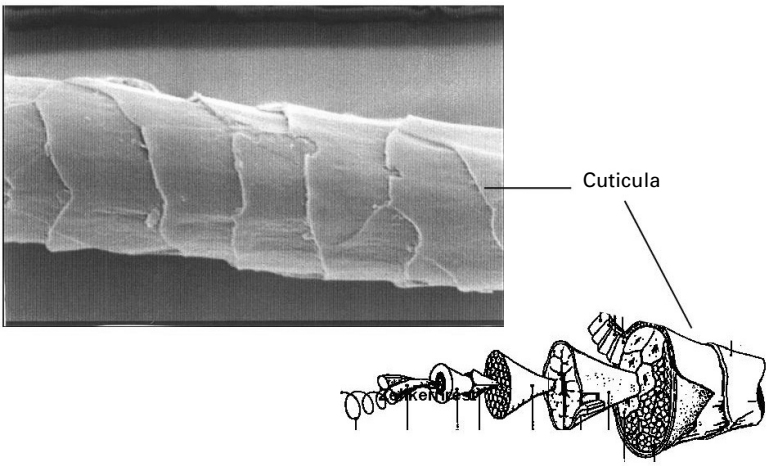
As quality requirements have increased over the years, mostly very fine wool is processed to fine knitwear or warm coats. Such fine quality of wool cannot generally be provided by domestic European sheep breeds. Consequently most wool is imported from Australia and New Zealand, where large herds of livestock are held.

Livestock auctions can make it difficult for yarn producers to trace the quality of the yarn back to the farmer and his practice of breeding. Until recently, wool was offered on the market only in anonymous lots, allowing no communication with the breeder (Kraft 2000). Considering ecological aspects, livestock husbandry can become critical for both the animals and the grassland they feed on. The grassland can be destroyed if the area for grazing is small, because the animals feed on the plants by pulling out the roots. Moreover, a very dense population on an area also increases the dissemination of illnesses and parasites among the sheep herd. Application of antibiotics and pesticides is often a consequence of too large animal herds on small areas. If pesticides are applied on the grassland, they will be stored in the animal's hair together with other artificial or toxic substances.

Sheep shearing takes place once a year. The hair is covered with the natural grease and sweat from the sheep, as well as with residues of dung and other particles. Such contamination accounts for 59.8% of the hair weight for Merino sheep and 21% in crossbred New Zealand sheep (Schäfer 2004).

For removal of these contaminations, and because it has to be stabilized in its dimensions, the wool hair is finished before the fibers are spun and woven or knitted. Any hot water treatment without finishing causes felting of the scale-type structure (see Fig. 2.29). The finishing process is divided into pre-treatment, dyeing and special treatment, the latter being carried out mainly at the fabric level (see under 'Finishing' in Section 2.7.1).

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2.29 Structure of the wool fiber. The 'shells' of the cuticula are crushed if the wool is exposed to high temperatures and mechanical friction (source: Schäfer 2004).

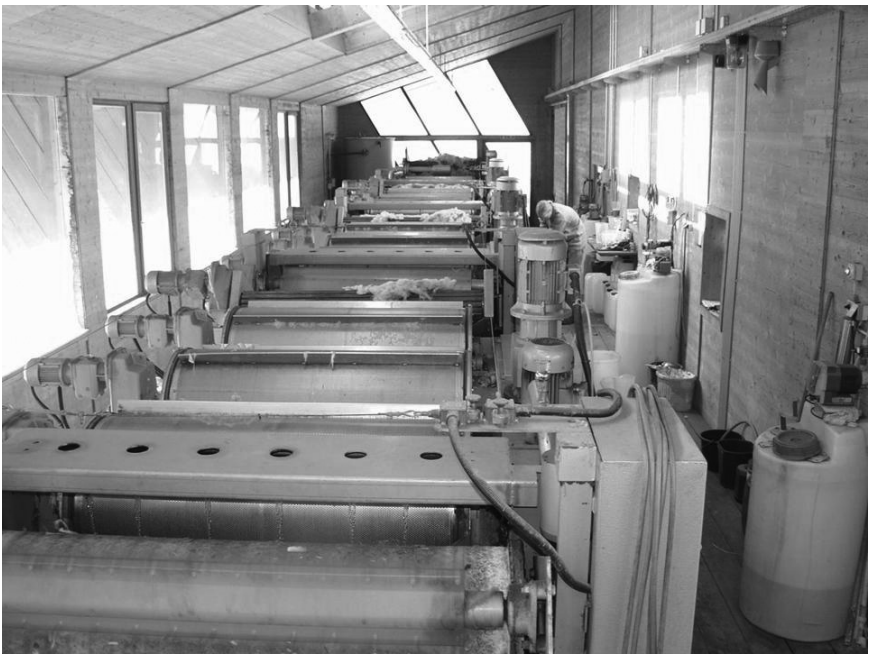
In pre-treatment, the wool is scoured, which produces large quantities of contaminated waste water. The animal grease can be extracted from the waste water and refined as a by-product called lanolin. The washing of wool, carbonization with Na_2CO_3 and non-ionic tensides is carried out in several successive baths (up to five), wherein the wool remains for only a few minutes and at a moderate temperature in the same bath (see Fig. 2.30). Higher temperatures and mechanical treatment would produce a felt through shrinking and entangling of the segmented wool hair. Therefore anti-felt treatment with chlorination and polymer finish is mainly applied. Dyeing processes include bleaching, whitening and dyeing, which is done mainly after scouring but can also be applied at the level of yarn or fabric.

Some Eastern European countries developed coarser wool qualities for their domestic need during the period of centrally planned economies. They are refining these qualities for the European market (Mihai 2004). In the USA, Texas developed the domestic wool supply in the nineteenth century, based on the Merino sheep imported from Spain (Carlson 2004). During war periods the production increased. Texas is still the main producer of the US domestic wool demand for angora and merino wool.

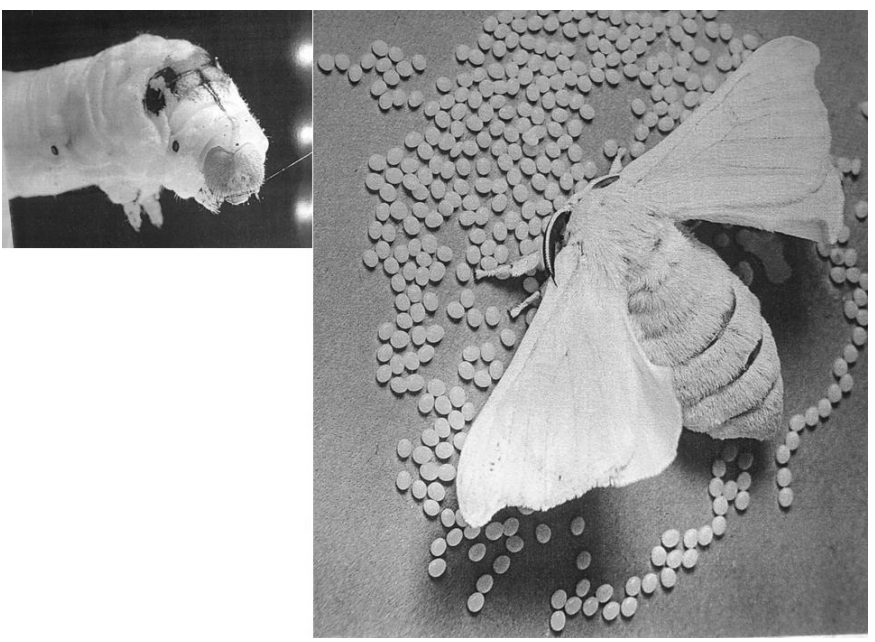
2.2.8 Silk

Silk is the only natural filament harvested from the silk spinner's cocoon (Fig. 2.31). Only so-called wild silk allows the harvest of the fine material without killing the larval insect inside the cocoon. All other silk is harvested

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2.30 The only facility for wool scouring in central Europe with five washing compartments.



2.31 Silk is the only natural filament harvested from the cocoon of the silk spinner moth, *Bombyx mori* (source: Haettenschwiler 2004).

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from silk farms where the insects are cultivated in millions. Most species have become extinct in nature due to the use for textile fibers. The silk spinner moths (*Bombyx mori*) from farms have degenerated and cannot survive in free nature (Bulgheroni 2002). Hence sustainable development had already failed in silk production long ago.

Development

Silk moth larvae have to feed on high quality leaves of the mulberry tree. One larva eats up to 500 g of mulberry leaves before changing into a pupa. The silk spinner larva produces two silk filaments by means of its two glands to form a cocoon around itself. The cocoon, formed to hide the animal for its metamorphosis, consists of two silk filaments, which represent the raw material for textiles and apparel. For optimal development, air conditioning is required for control of appropriate temperature and moisture content. In this way development can be synchronized and production optimized. Besides silk growing on an industrial scale, there is still small-scale production by some farmers who grow silk moths on a few mulberry trees. For commercial farming, mulberry trees are grown in monocultures and require continuous treatment with pesticides. The pesticide is taken up by the silk moths, left in the soil or transported to the atmosphere.

In further processing, the silk cocoons are treated with hot steam, whereby the sericin, a gluing substance, is removed. The next process is reeling, mainly carried out manually in Asia, whereby six to seven filaments are aligned. High quality silk shows a high degree of uniformity, although the individual silk filament decreases in diameter as its length increases (see Chapter 3).

Silk is consumed not only as long filaments in its highest quality as reeling silk, but in various by-products such as reeling silk, bourette and finally silk dust for cosmetic or medical purposes. Table 2.6 gives a rating of environmental impacts (Bulgheroni 2002, Haettenschwiler 2004).

2.3 Man-made fibers and filament and yarns

Man-made fibers are divided into fibers based on crude oil fractions (synthetic fibers) and fibers based on regenerated cellulose (cellulosic fibers). Figure 2.32 gives an overview on the different fiber types. For a few decades, use of synthetic fibers increased only slowly due to some properties making them inferior to cellulosic fibers for apparel production. However, fiber innovation in the area of synthetic fibers brings new fibers on the market (see Chapter 3).

Today the most prominent fibers for apparel are polyester (PES), followed by polyamide (PA), cellulosic fibers (CV), acrylic (PAN) and others including polypropylene, elastic fibers, polyvinylchloride, polyvinylacetate, etc. (see

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Table 2.6 Impacts of silk breeding in Thailand: 5 = large impact, 0 = no impact

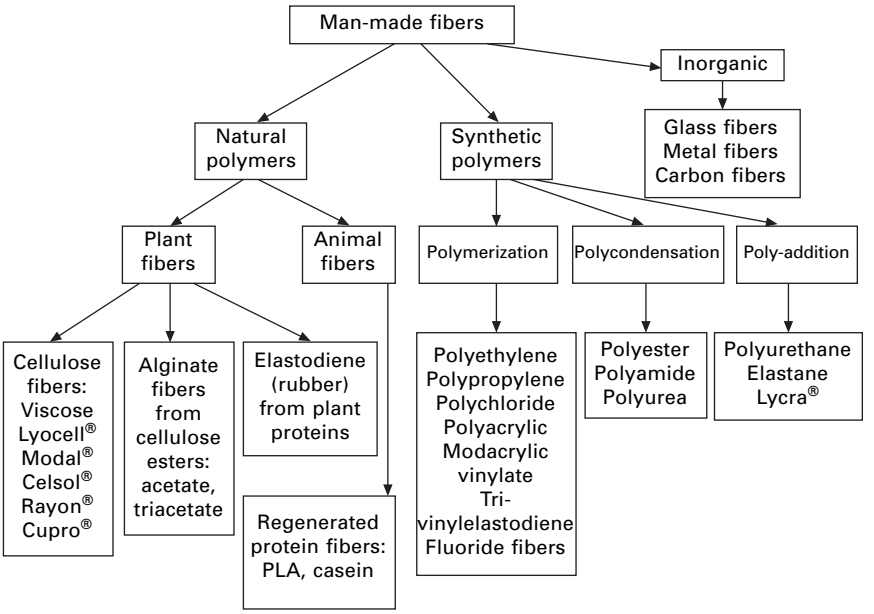
Process	Environmental indicators	Significant impacts
Growing	Soil exhaustion	4
	Water consumption	5
	Pesticides	5
	Energy	2
	Killing pupae	3
	Cocoon failures	0
Reeling	Effluents	4
	Energy	3
	Waste	0
Twinning	Energy	3
	Waste	0
Spinning	Energy	5
	Waste	0
Finishing	Effluents	5
	Chemicals	5
	Energy	5
	Contaminated air	3
Transport	Energy	5
	Emissions	5

Fig. 2.33). The worldwide share of synthetic fibers has increased tremendously since 1990 and has passed that of cellulosic fibers by far.[9] By the turn of the century the success of man-made fibers became obvious, even if the growth of the demand is different for the individual fiber types PES, PA, acrylic and cellulosic fibers. Man-made fiber producers are developing enhanced fiber properties by changing their chemical structure (see Chapter 3).

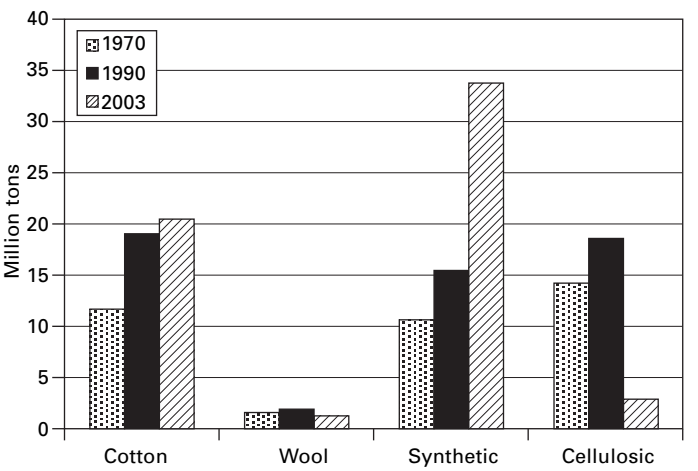
There is a difference in fiber production and mill consumption in general and specifically for individual fibers. Polyester consumption is and was higher than production, meaning there is an increased trend for imports from other parts of the world. The fiber demand in general increased, while the demand for polyamide decreased from 1990 to 2003 with a slightly higher production in 1990 and an inverse trend in 2003. Acrylic fiber production has decreased within the last decade, but mill demand was always lower. Consequently, fibers were consumed by mills outside Europe. The trend in cellulosic fibers follows that of acrylic fibers. The only growing area is in newer fibers like polypropylene and elastic fibers, the latter with a complex production process to introduce the desired properties (see Chapter 3). It will only be a question of time until the production of these high-tech fibers moves towards Asia.

[9] www.cirfs.org

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2.32 Systematics of man-made fibers according to their chemical structure.



2.33 Development of worldwide fiber production.

All man-made fibers are processed to filaments of different spinning types: wet spinning and melt spinning. Filament yarns are specified by their so-called titer as follows:

Titer = fineness (denier) × number of filaments

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where denier = weight in grams per 9000 m length. A titer of 360 × 30 means the fineness of the yarn is 360 denier and it consists of 30 filaments. Filaments can be cut into staples for blends with natural fibers.

2.3.1 Melt-blown fibers (polyester)

The principle for the production of synthetic fiber such as polyester is based on crude oil fractions, from which so-called monomers are constructed by means of chemical reactions. The first process is steam cracking of oil, providing several fractions, whereby the magnitude of the individual fractions is controlled by catalysts. The chemical molecules are changed in such a way that they possess the necessary docking positions for further processing. This requires several chemical reactions until the monomer is constructed. These monomers are processed to build chains with reaction types like poly-addition or polymerization, to mention the most common ones. Polymers are traded in the form of pellets from which fibers are gained by melting and extrusion. The example of polyester stands for synthetic fibers.

Production of raw material

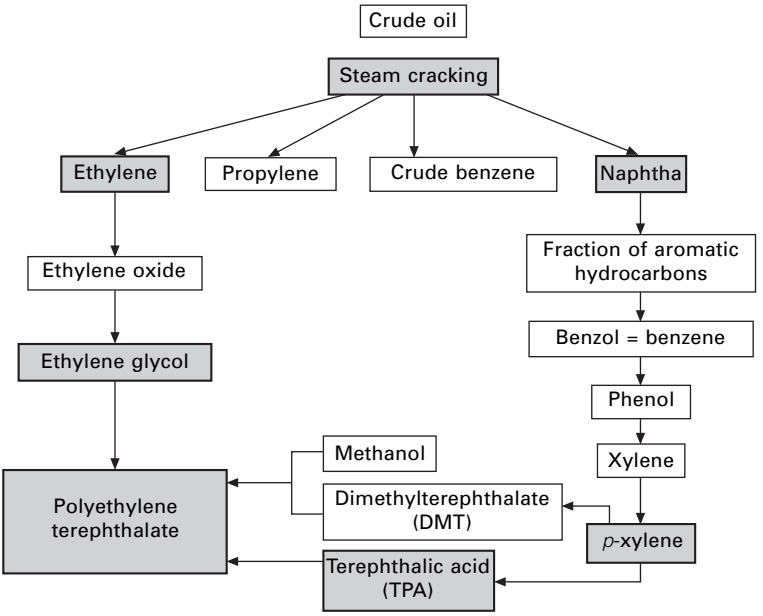
The base for polyesterterephthalate is crude oil, specifically ethylene and naphtha, gained as fractions by steam cracking. The fractions are further processed to ethylene glycol and xylene. Two different technologies have been developed, namely processing of xylene to dimethylterephthalate (DMT) or to terephthalic acid (TPA). The terephthalic acid technology is considered to be more environmentally friendly; however, it has only been feasible after a proper separation of *p*-xylene was achieved. Further reaction (re-esterification) of DMT or TPA with ethylene glycol and polycondensation provides polyester terephthalate (PET). In most cases granola is formed if the material is not spun in place (Fig. 2.34).

Improvements for environmental concerns are to be found in reduction of energy use and substitution of harmful catalysts (Pfister 2002), as all exothermic chemical reactions are based on energy supply (temperature, pressure) and/or catalysts, which mostly consist of heavy metals.

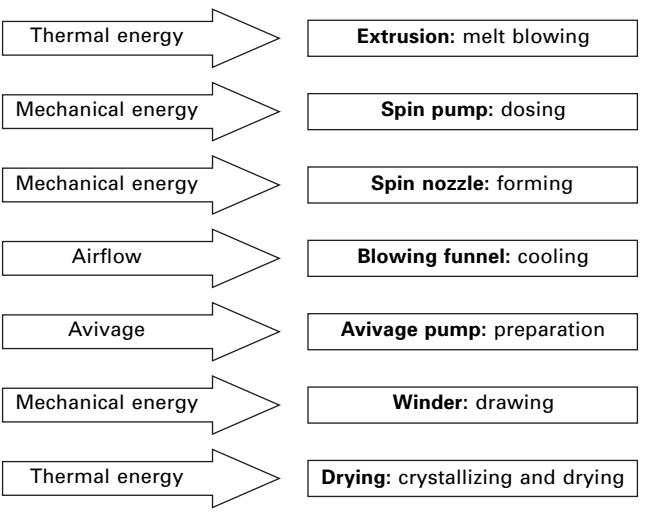
Melt spinning (polyester, polyamide, acrylic)

Melt spinning is applied to the raw material of polymerized plastic such as polyester, polyamide, polypropylene, etc. The granola is melted at a high temperature, depending on the melting point of the material (PES = 274°C) (Fig. 2.35). Constant temperature of the material is essential for processing in the winding alley, which is achieved by means of a surrounding bath

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3.34 The two production lines for TPA, the monomer base for polyester.



3.35 Melt spinning processes with inputs, equipment and processes.

(diphenyl) in a closed circle. For polyester a limited number of dyestuffs can be added in this process (spun dyed).

The winding alley delivers the melt to 6–8 spin pumps. Each spin pump

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constantly provides an exact dose of melted material according to the desired titer (diameter in relation to fineness) of the filament. The melt is pressed through spin dosage plates. These metal plates consist of precisely formed circular microtubes in a variety of numbers (giving the number of single filaments). For specific shapes of microfibers, tubes with different profiles are available, giving them the desired fineness of the monofilament and shape for specific application. The melted material is pressed through the tubes, forming filaments by falling through the 3–4 m deep airflow zone, driven at its starting point by gravity force. At the lower end of the shaft the filaments from each spin dosage are individually collected and wound over a powered winder, drawing the yarn.

During the passage of the quench zone the filaments are cooled and frozen by means of laminar airflow. Avivage (lubricants, tensides, oils, etc.) in form of emulsion is applied for improved fiber gliding, prevention of fiber damage, antistatic properties and so on.

Chemical fibers, as produced by the melt spun process, do not yet show the properties required for textile processing. Only by the drawing process, whereby the yarn is extended to a multiple of its original length, can properties like strength, modulus and shrinkage be achieved.

Environmental indicators

Environmental indicators for wet spinning are given in Table 2.7. Energy consumption, being the highest input, depends on the energy management of the individual plant including technology, heat recovery and energy supply.

2.3.2 Regenerated cellulosic fibers (viscose)

Viscose, Lyocell®, Rayon® and Celsol® are a selection of brands of man-made fibers, based on cellulose material, whereby the structure of the plant is dissolved. The material, once generated as replacement for silk due to

Table 2.7 Environmental indicators in filament spinning

Input	Output
Granulate	Solid polymer
Spin liquid (cellulose)	Yarn waste
Spin bath (chemicals)	Effluents with chemicals from spin bath
Electrical energy	CO_2, NO_x, SO_2 (airborne emission)
Fossil energy	CO_2, NO_x, SO_2 (airborne emission)
Compressed air	Contaminated air
Godets	Metals (solid waste)
Mechanical parts (replacement)	

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the scarcity in World War II, has improved in quality, but still represents only 4.4% of world fiber consumption in 2003. Most cellulosic fibers are produced in Asia, while in Europe production declined from 1980 with 1.9 million tons (a world share of nearly 60%) to 0.9 million tons (17% of the global production of fibers, produced in 27 plants).

Raw material

Resources for cellulose are plants, mainly stems from trees. The first processing steps to pulp are the same as for paper production. Wood is a renewable resource; however, there are some ecological aspects to consider in forestry. Fragile natural ecosystems may be damaged if huge amounts of one species are harvested. If traditional heavy machinery is applied for tree cutting, the area is covered by a system of tracks through the forest. This has a profound impact on small plants and animals. If the area is big enough, the water regime will be changed towards swampland, because large trees have a high throughput of water, sucking it from the soil and delivering it to the air by means of transpiration. Both the mechanical impact of the harvest machinery as well as the change in the water regime can lead to loss of species and thereby to losses in biodiversity. In Nordic regions, where natural ecosystems consist of only a small number of highly adapted species, such changes are even more dramatic. The wetland created is often not suited for reforestation, and badland remains. If reforestation is possible, very often monocultures of the desired fast-growing species are planted. But there are ecological options in machinery and forestry: newly developed machinery for forestry not only allows much more careful harvesting with only superficial impact on the soil, but is also multifunctional in processes: the stems are harvested by a cut near the root, bark is removed, and the debarked stem is cut into pieces of a desired length.[10] A mixed system of small plantation areas for harvest between areas of undisturbed natural wood conserves the natural ecosystem by migration of species into the harvested area.[11] The Forest Stewardship Council (FSC),[12] developed by the WWF, supports forestry in its changes towards sustainable development by setting ecological standards and certifying production.

Transportation is always a critical point. If raw material grows a great distance from where it is needed, long transportation becomes necessary, contributing to global warming by emission of greenhouse gases as a major impact. In Canada and Nordic countries, the large rivers are used for rafting

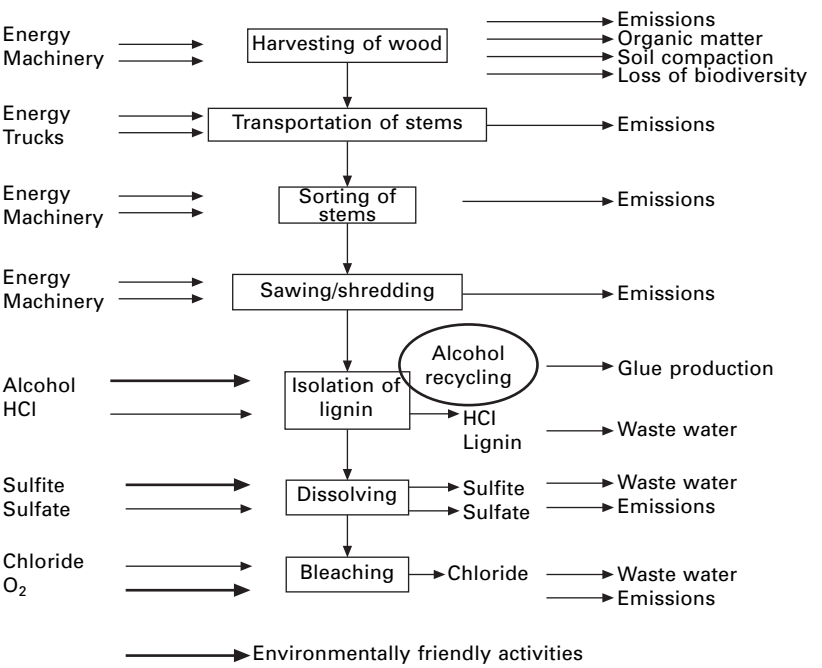
[10] Harvest demonstration by Regi-Holz, Ottikon, Switzerland.
[11] Projects Ecoforest Panama (http://research.yale.edu/) and Precious Woods (www.preciouswoods.ch).
[12] www.fsc.org

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the tree trunks, bringing the material to the sawmill. Where such an ecological system is not available, trucks serve for transportation. But most preferably wood is cut for local consumption, in order to reduce transportation costs and additional processes (such as transformation of wood pulp into sheet form for transportation).

Trunks and branches are mechanically processed by a shredder and further processed by means of hydrochloric acid (HCl), or preferably alcohol, allowing removal of the lignin. In ecological processes the lignin is incinerated and its inherent energy used for heating processes. In the alcohol-based process the solvent can be used in a closed loop by recycling, while HCl is dumped to the effluent, requiring neutralization treatment with alkali. In the dissolving process either sulfate (H_2SO_4) or preferably sulfite (H_2SO_3) is supplied to the wood mass in a batch process, resulting in wood pulp and contaminated effluent. The application of sulfite is preferable to sulfate, due to its faster and less toxic degradation in the effluent. Peroxide should be the choice for bleaching agent, because the alternative, chlorite, causes a heavy effluent contamination with a high ecotoxicity (Schmidtbauer 2000) (see Fig. 2.36).

Preparation of pulp for transportation includes pressing into sheets and packaging. Before further processing to cellulosic fibers, pulp is dissolved in NaOH, whereby the yarn properties are influenced by temperature and



2.36 Process overview of pulp production for viscose generation.

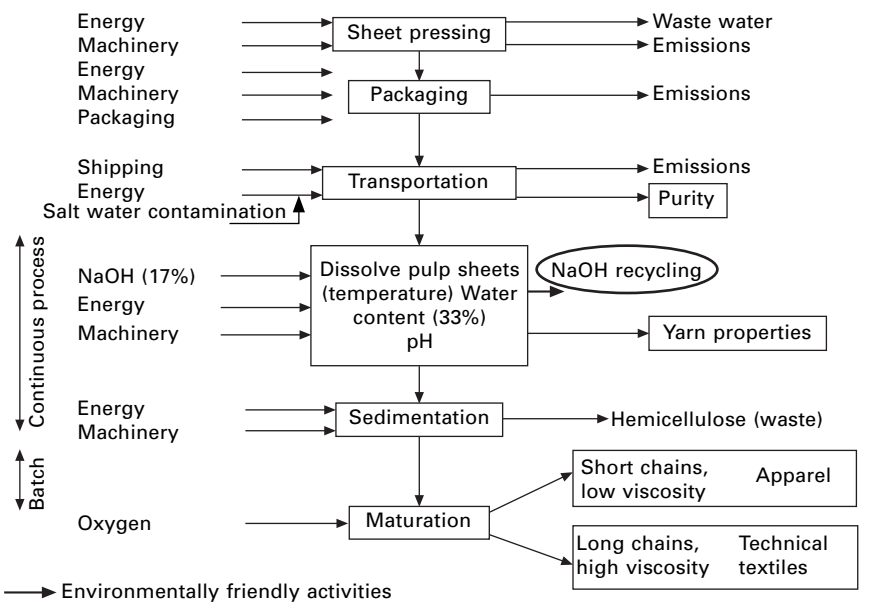
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pH conditions of the process. In sedimentation the so-called hemicellulose is removed, and the mass is exposed to oxygen in a batch process. The time of this 'maturation' process defines the length of the molecular chains and thereby the viscosity. For apparel, low viscosity is desired, achieved by longer maturation time, while technical textiles require high viscosity (see Fig. 2.37).

In classical viscose production the bleached wood pulp is exposed to carbon disulfide, CS_2, whereby the mass is sulfidated to xanthogenate. Due to the extreme explosive potential of CS_2, the process is carried out in a nitrogen atmosphere and with high precaution measures. The alternative Lyocell production is based on the NMMO process (see Chapter 3). Another alternative viscose, Celsol® (Struszczyk 2002), can be produced without CS_2, minimizing the risk in transportation and in the production plants. In both processes large amounts of NaOH are applied for stabilization. The mass is deaerated and carefully filtered for a high purity and increased quality of the viscose (see Fig. 2.38).

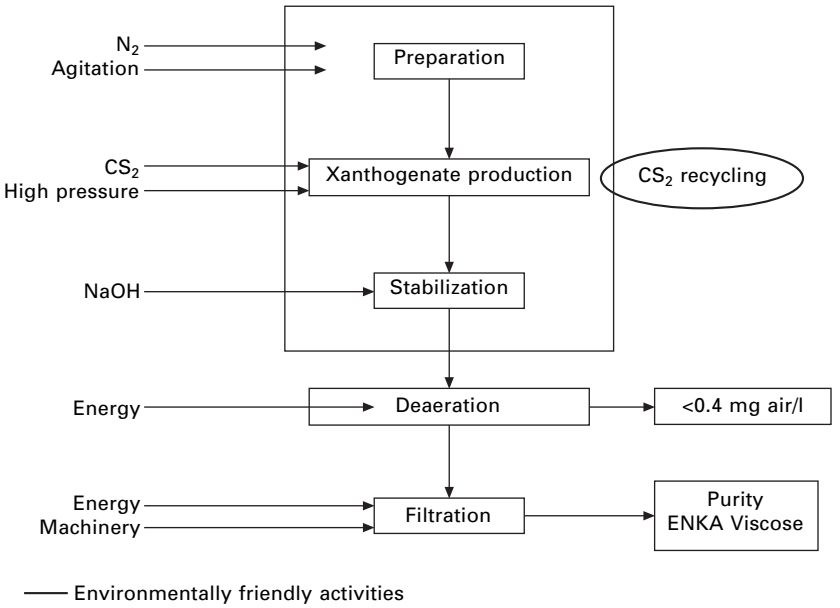
Wet spinning

Regenerated cellulose fibers are produced in a wet spinning process. The base for this process is the highly viscosic liquid, extracted from the pulp material, xanthogenate. In the wet spinning process a filament is drawn by



2.37 Processes for viscose preparation from pulp.

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2.38 Xanthogenate sulfidation processes in viscose production, a highly sensitive process with high requirements for working safety.

injection of the xanthogenate into a stabilized bath with H_2SO_4. Thereby H_2SO_4 is reacting to Na_2SO_4, which either produces a waste (sodium sulfate) or is recycled to H_2SO_4 in an additional process. The properties of the fiber and yarn are generated by settings in the drawing process, washing and application of lubricants (Fig. 2.39). Viscose is applied as filament yarn or is cut to staple fibers. Similar processes are carried out for cellulose materials of other origin.

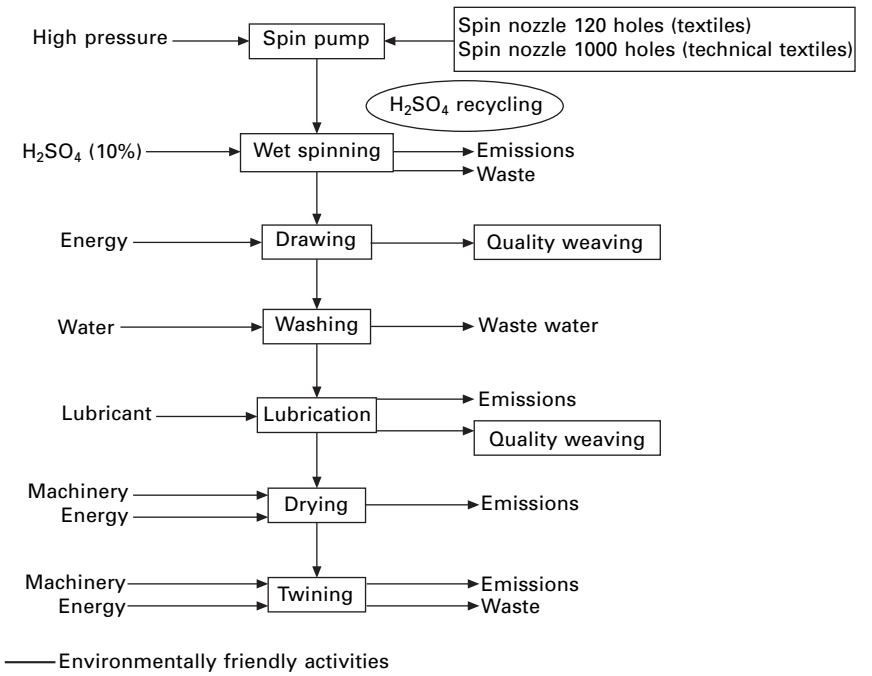
2.3.3 Fibers from polylactic acid

Among the so-called regenerated man-made fibers, polylactic acids, gained from corn starch or animal proteins, will represent an important fiber for the future. Their renewable resources are available on a large scale and often represent a by-product, if not a waste. Such fibers represent a sustainable solution. However, the regeneration processes with Ingeo do not yet run economically on an industrial scale of >100,000 tons per annum (Vink 2003, Lips 2001).

2.4 Energy

All textile processes require a considerable amount of energy, from fiber production up to finishing. Energy is a natural resource, renewable or

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2.39 Viscose production processes: wet spinning.

non-renewable, which can be converted into other forms according to the thermodynamics. Prime renewable energy sources are hydropower, wind power and solar power, generally used for electricity production, as well as wood pellets and other plants which are used in combustion. Non-renewable energy resources are crude oils, gas, brown coal, etc., prime sources that were formed on the planet over millions of years. Nuclear power takes a special position as its by-product, the hazardous nuclear waste, requires tremendous time periods to degrade. Conversion from one form of energy to another is more or less efficient, depending on the exergy value, the losses by transformation to energy forms (e.g. heat) which cannot be utilized in the system.

2.4.1 Prime energy sources

Energy use has a dominant environmental impact in textile processing. All machinery in textile processing requires electricity for driving or winding. However, a considerable number of processes are based on fossil fuels: in rural areas for agricultural systems, but also in finishing for steam production. Table 2.8 gives an overview on energy types in textile processes.

Electricity is provided by national energy suppliers, whereby the prime

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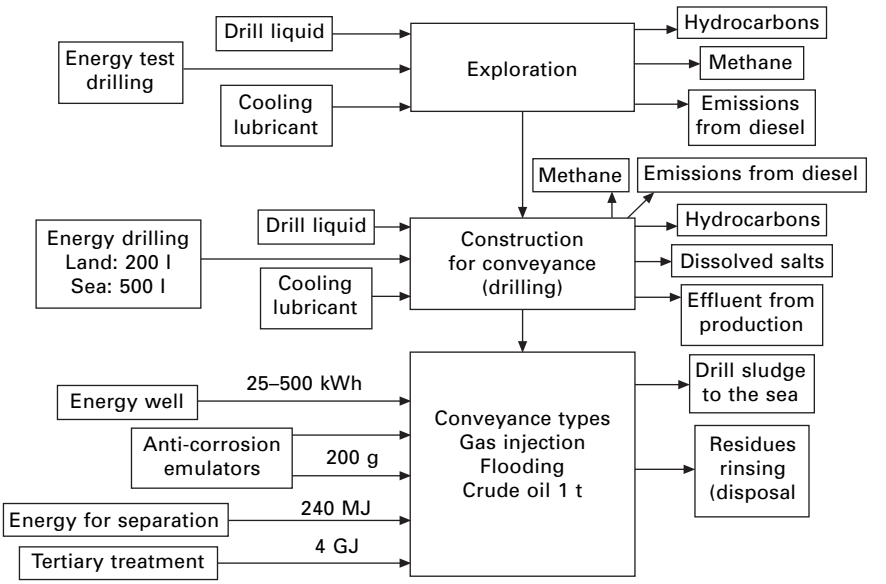
Table 2.8 Energy-using processes in textile production

Value-added chain	Process	System	Energy type(s)
Cotton growing	Irrigation system		Fossil fuel
	Tractor engine for tillage and harvest	Traction system	Fossil fuel
Cotton ginning	Gin stand, lint cleaner	Drive system	Electricity
	Fiber transportation by air	Air compression	Fossil fuel
Crude oil refining	Crude oil fraction	Steam cracking	Fossil fuel
Polymerization	Chemical reaction		Fossil fuel
Filament spinning	Melt spinning	Heating, pumping	Fossil fuel
		Drive systems	Electricity
	Wet spinning	Drive systems	Electricity
Cotton spinning	Machinery power supply	Traction and drive systems	Electricity
	Transportation system	Air compression	Electricity
	Aeration	Air conditioning	Electricity
Weaving and knitting	Machinery power supply	Traction and drive systems	Electricity
	Aeration	Air conditioning	Electricity
Finishing	Machinery power supply	Traction and drive systems	Electricity
	Process temperature	Steam production	Fossil fuel
	Drying	Aeration	Fossil fuel
Manufacturing	Machinery power supply	Traction and drive systems	Electricity
Transportation	Truck, ship, airplane	Drive systems	Fossil fuel
	Train	Traction systems	Electricity
Illumination	All processes	Infrastructure	Electricity
Heating	Cold climates	Infrastructure	Fossil fuel
Cooling	Hot climates	Infrastructure	Electricity

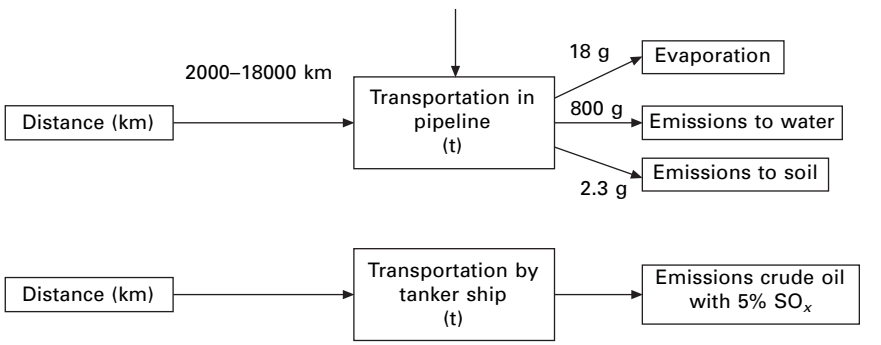
source mix depends on availability and political decisions. Energy supply is one of the most prominent resources for textile processes and is strongly related to the environmental impacts on climate change, as calculated in life cycle assessment (see Chapter 4). Renewable energy sources are preferred if possible, evaluating also alternative sources. However, many long-established textile companies set up their own hydropower-based energy supply, an environmentally friendly energy source.

Among fossil fuels (crude oil and gas as main sources) the choice should be for gas because of the lower impacts in its life cycle compared to crude oil. The exploration and conveyance of fossil energy is associated with considerable environmental impacts, in which gas is the more environmentally friendly solution (BUWAL 2000). As presented in Figs 2.40 and 2.41, exploration, construction, conveyance and transportation are the main processes.

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2.40 Gas exploration and conveyance.



2.41 Environmental impacts associated with pipeline transportation.

High amounts of energy are associated with emissions, besides methane emissions in exploration. Dissolved salts, drill sludge and rinsing residues are the main output indicators, together with unknown losses of crude oil along the long-distance pipelines.

2.4.2 Energy efficiency

Many processes have been automated in industrialized countries, from cotton growing to sewing. The efficient use of machinery relies on best technology of efficient drive and heating systems combined with good maintenance in

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production (see also BAT, Section 3.11 in Chapter 3). On the other hand, quality and productivity are a driving force in machinery development. The energy consumption of a company is based strongly on product quality: the energy consumption of a spinning mill is related to the fineness of the manufactured yarns and should not be calculated per kilogram, because the production of 1 kg of fine yarn requires much more energy than the production of 1 kg of coarse yarn.

2.5 Yarn production

Spinning processing is different for staple fibers and filaments. A staple fiber yarn is produced by twisting, entangling and embedding a certain number of fibers in order to get a longitudinal construction of a defined fineness, strength, elasticity and structure. Staple fibers are gained from all natural fibers (except silk) and from man-made filaments that are cut in staple. Several technologies have been developed for staple spinning and filament spinning. The spinning technology sets the shape of the yarn body, which can be further influenced by individual yarn construction. The desired quality is defined in yarn quality parameters for suitable communication with fabric production (Chapter 3).

2.5.1 Staple fiber spinning

Spinning preparation

Before the actual spinning process, the baled fibers have to be opened and cleaned. A bale is a package of about 220 kg cotton, densely pressed for efficient transportation. Bales of different fiber quality are arranged in a specific order to equalize fiber quality. Layer by layer the fibers are removed from the pressed bale by means of the bale opener, working horizontally over the bales (Fig. 2.42).

Transportation of the fiber throughout the whole blowroom is carried out by air suction. Two to three cleaning steps remove dust and trash as well as foreign matter from the fiber: in a 'coarse' cleaning process, fibers are separated from other materials by means of an assembly of pins, beating the fibres, and by separating them by centrifugal force in a rotating cylinder. To equalize the fiber quality throughout, the flakes are fed into a mixer, where fibers from different bales are mixed after passing through channels of different length. Cotton fibers removed from an upper position of bale opening are mixed with fibers removed from a lower layer. The mixer generally is situated between the two cleaning steps. In this step an optical device for the detection of foreign matter can be installed additionally. It is 'cutting out' fractions of fibers, contaminated by non-cotton material, which could

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2.42 Cotton bale opening. The specific layup of the bales enables the production of a desired quality.

produce harm to the spinning equipment. In the last 'fine' cleaning process the fibers are moved over a rotating trimming drum, allowing a separation of dust particles by weight. At the end of the blowroom processes the fibers are clean and organized in loose flakes.

Carding

In the card the randomly oriented fibers of a flake are brought in alignment and form a so-called web of parallel fibers. The drum, with a coating of fine teeth, picks up the individual fibers and delivers them oriented parallel to the doffer cylinder. The sliver is formed by collecting the whole width of the carded fibers to a strand of diameter 1–2 cm (Fig. 2.43).

The sliver's diameter is measured as fineness (tex), defined as 1 tex = 1 g/km. Typical fineness of card slivers is 5000–6000 tex (for cotton). Although there is no twist in the fibers they form a loose contact, allowing storage in loops of slivers in cans for further processing. A detailed process scheme is given in Fig. 2.44.

Drawing

The process of drawing aligns 6–8 slivers from individual cans and defines the fineness of the sliver by regulating the speed of drawing. The process

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2.43 The carding process in cotton spinning for sliver production. The sliver has a fineness of 5000–6000 tex.

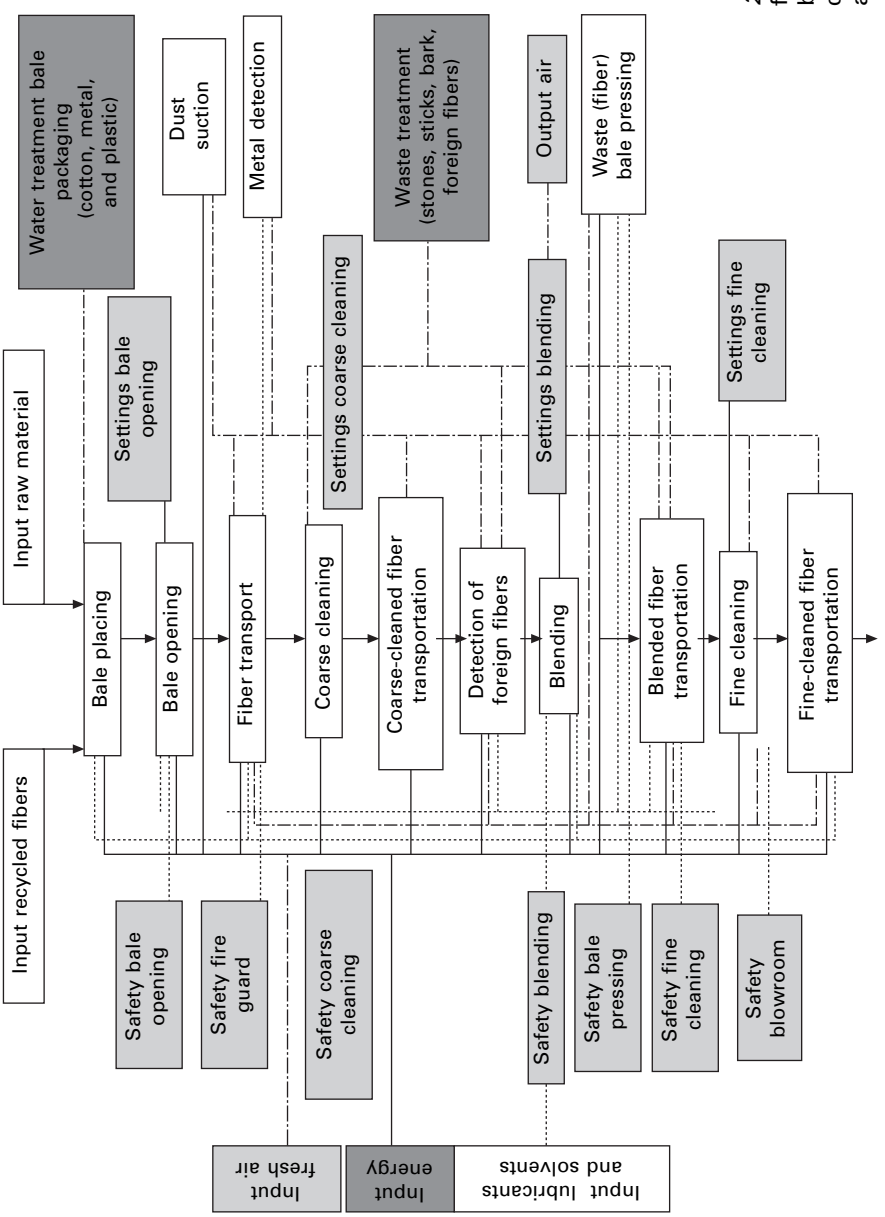
again mixes the fibers from different cans. Here also blending of fibers can be achieved by the arrangement of cans with different staple fiber types (polyester, viscose, etc.). The drawing speed improves the orientation of fibers within the sliver.

Ring spinning

The ring spinning process splits up into three sub-processes: roving, ring spinning and winding. The diameter of the sliver is reduced in two steps in roving and ring spinning. Reduction in fineness is achieved by drawing of the sliver, whereas the twist of the fiber builds the yarn characteristics like tenacity and breaking elongation. On the flyer machine, a twist of 2 alpha (m) is introduced for easy handling, and the roving of 500–600 tex is wound on a roving package. On the ring spinning machine the roving is drawn to the desired fineness of the yarn and a defined twist is introduced. For knits a low twist coefficient of 65 to 90 alpha (m) is introduced, while twist of warps for woven fabrics is between 100 and 150, and for filling between 75 and 115. The lower values count for longer staple cotton, the higher values stand for short staple cotton. Ring spun yarn is wound on cops, each being a package of 50 to 80 grams. Consequently these cops have to be spliced when rewinding on larger cones, whereby a quality check is carried out. Failures like thick and thin places are detected and cut out, and the yarn ends are spliced by means of an air jet.

Three options in staple fiber technology have to be mentioned: rotor spinning

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2.44 Process tree from bale opening, blowroom to carding with inputs and outputs.

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as an alternative for coarser yarns; compact spinning as a development based on ring spinning for high quality yarns; and air jet spinning, the newest development (see Chapter 3). Spinners often develop products with fiber blends (Blumer 2003, Mankowski 2004).

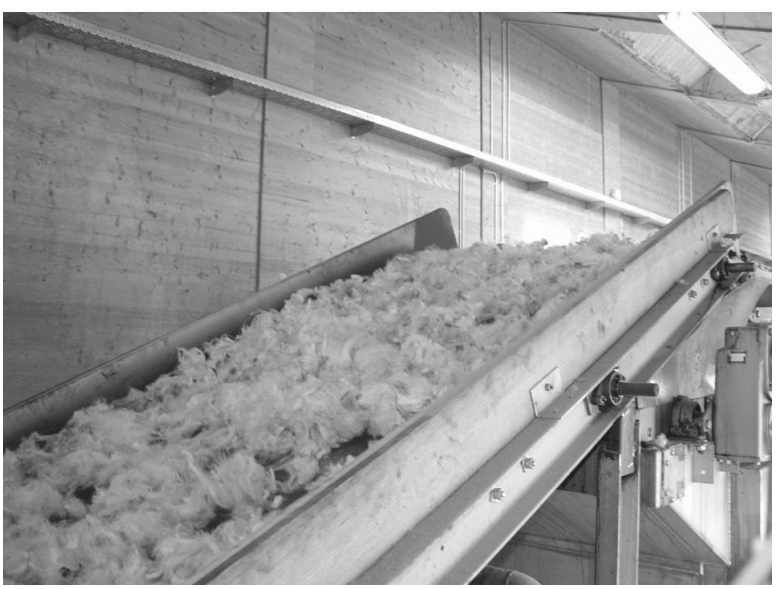
Wool

Wool fibers are considerably longer than cotton fibers. Yet, the principle of staple fiber spinning is the same as for cotton. The raw material (Fig. 2.45) is flocks of washed, scoured and carbonized wool (see Sections 2.1 and 2.4).

Spinning of wool fibers is carried out on similar machinery as for cotton, shown in Fig. 2.46. Wool spinning technology used to be much more important in historical times, while the share of cotton was smaller. Today technology for wool is much less productive than cotton spinning due to the small market share of wool (about 5%).

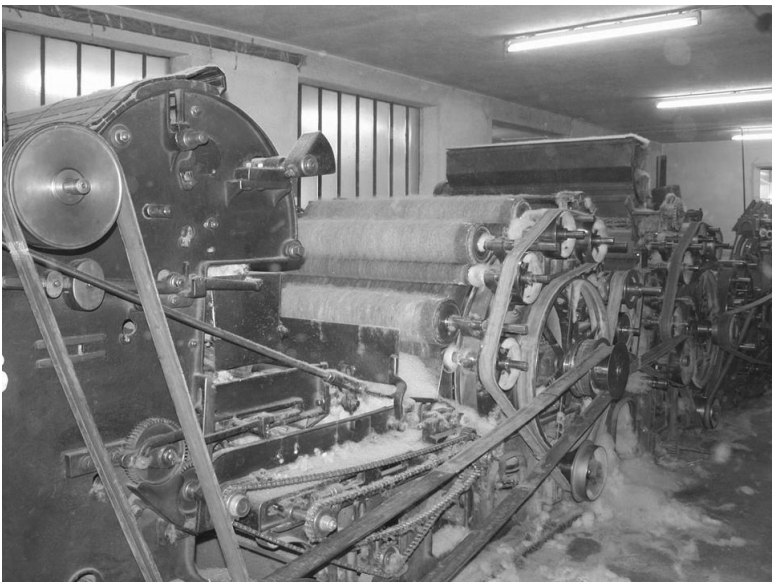
Environmental indicators

Spinning preparation (bale opening and carding) produces a number of environmental impacts, based on inputs and outputs of the processes (see Table 2.9).



2.45 Flocks of scoured wool fibers before carding (source: Regensburger 2004).

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2.46 Carding of wool fibers (source: Regensburger 2004).

Table 2.9 Environmental indicators in staple fiber spinning

	Input	Output
Bale opening	Energy	CO_2, NO_x, SO_2 (airborne emission)
Cleaning	Air	Dust particles (flammable)
	Recycled fibers	Foreign fibers
		Stones, bark, stalks
		Short fibers
		Packaging material (fabrics and bonding)
Carding	Energy	Garbage
	Air	Dust
		Fiber waste (recycling)
		Fiber waste (incineration)
Ring spinning	Bobbins	Fiber waste (recycling)
OE spinning	Cops	Fiber waste (incineration)
	Energy	Yarn waste
	Air	
	Water	
	Wax	
Packaging	Plastic	Plastic waste (recycling)
	Pallets	
	Energy	

Air is applied for transportation and is filtered at the end of the process. The outputs are several fractions of filtered material. Further impacts can be reduced by optimizing energy consumption and recycling of fibers on the

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input side. The output indicators are highly influenced by the cotton quality purchased and the market segment the spinner operates in. The amount of natural contamination cannot be influenced by the spinner. He chooses the quality segment of his yarn, particularly the fineness, whereby he sets the amount of fiber waste. For a combed quality this may result in up to 18% of the raw fiber mass. The amount of yarn waste is related to the quality of the available and purchased cotton fiber. Generally fiber waste is primarily recycled into the previous processes and secondarily handled as a by-product for products with lower quality requirements.

The main environmental input indicators of the spinning processes are energy, bobbins and cops besides water for air conditioning. On the output side there is waste of fiber and yarn as well as packaging materials. Compressed air is applied for conditioning of the yarn and removal of fiber contamination of the air. It is filtered at the end of the suction and conditioning processes.

2.6 Fabric production

Fabrics are produced as a two-dimensional arrangement of yarns or fibers. In woven fabrics two yarns are oriented at right-angles, while knitted fabrics are formed with yarn loops with an orientation in all directions. Non-woven fabrics are produced with unoriented fibers.

2.6.1 Woven fabrics

In weaving processes a two-dimensional fabric is produced, consisting of length-oriented yarns (warp) and cross-oriented yarns (weft or filling). The process is divided into three main sections: weaving preparation, weaving and fabric control, each consisting of different sub-processes (see Fig. 2.47).

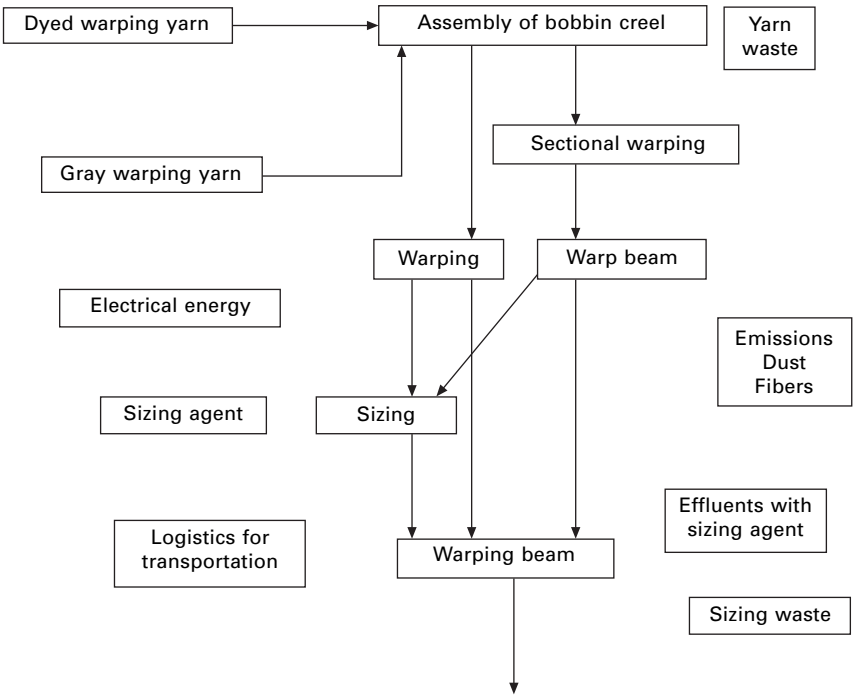
Processes

Beaming and sectional beaming

In the weaving preparation, the warp of the desired length and density of the fabric is produced. For every warp yarn, a bobbin with the desired quality and length has to be prepared. All bobbins are arranged in a large gate to be wound in parallel on a beam (Fig. 2.48).

Because the bobbins do not consist of exactly the same length of yarn, the leftover yarns have to be spliced for reuse, mainly as weft yarn. If the density of warp yarns is very high, the beaming process has to be carried out in sectional warping, each consisting of a number of warp yarns (Fig. 2.49). The reason for this procedure is the dimension of the creel for a limited number of yarn bobbins. Sectional warping is also applied for fabrics with

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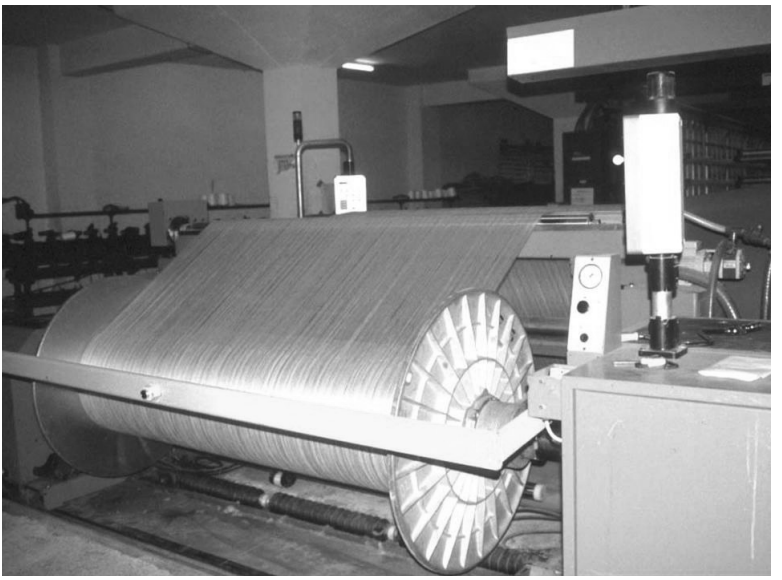


2.47 Weaving preparation processes.



2.48 Weaving preparation: creel with yarn cones.

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2.49 Sectional beaming and assembling.

different colors in the warp. The warp yarns have to be oriented strictly parallel in order to prevent any yarn breaks (ends down) in the weaving process, which is achieved by a controlled winding of the warp.

Sizing

In the weaving process the warp is mechanically stressed, due to abrasion within the lamella, strand and reed as well as through rapidly changing tension forces. Abrasive damage is more critical with staple fibers (cotton) and loose filament yarns (microfibers, texturized yarns). Sizing provides the warp with a certain strength by compacting the fibers with a glue. The application technology and formula have to be adapted to the yarn type. Special wetting or corona treatment provides increased protection of the warp. The sizing agent is prepared in the weaving mill and is applied to the warp immediately before weaving. Consequently this process can be combined with the assembling of warps, by dumping a section in a tank and drying it between heated cylinders.

Reeling

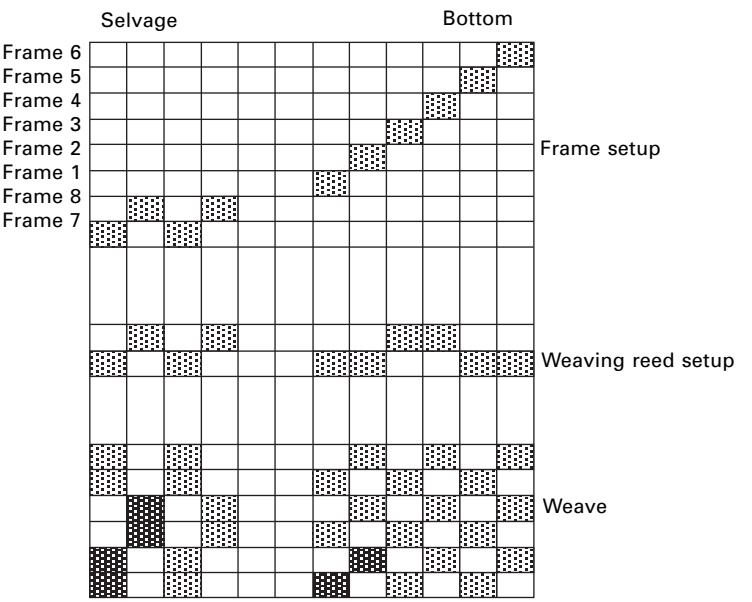
The shorter a warp, the less economic the fabric becomes, due to the high amount of (manual) work in preparing the warp. Standardized warps, which can be produced in greater lengths, are to be favored. The reeling of the

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warp beam is a labor-intensive process, especially if performed manually. A good production plan allows machine knotting of subsequent fabric with the same number of warp yarns. If a beam has to be reeled completely, this means individual inserting of the warp yarn through the lamella, the strand and the reed. In manual work this requires 4–5 days; if automated it can be achieved within a few hours. The reeled warp is brought to the weaving machine to be fixed to the looms. This process requires another few hours in which the weaving equipment is not productive.

Weaves and patterns

Weaves are defined patterns of the warp and weft yarn crossings in order to stabilize the fabric. The fewer crossings are defined in a weave, the more dense becomes the fabric. Woven fabrics are specified by the weight per m^2, ranging from 5 g/m^2 up to 500 g/m^2 and more, depending also on yarn fineness and counts per cm in the warp and weft dimension. The simplest woven fabrics are produced in canvas weave of one color; the most sophisticated are produced by a jacquard system, allowing any possible pattern of colors. Patterns are created by textile designers, who combine colors and weave types (Fig. 2.50). The design has to be adapted to the chosen machine by addressing the warp yarns adding to the weave reed setup and the looms.



2.50 Example of machinery setup of a canvas fabric on a weaving machine.

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Countless options for patterns in different weave types are developed by designers (see Chapter 3). In production the desired design has to be adapted to the available equipment, preferably based on the technology portfolio of the company.

Weaving

In the weaving process the frames are lifted according to the specified weave and pattern. The frames are individually lifted to form sheds, in which the weft yarn is inserted across the warp direction (Fig. 2.51). After each insertion the weft yarn is beaten densely to the woven part to achieve the required density of the fabric. Specific weaving technologies are available (see Chapter 3). In all technologies, except for the shuttle loom, the weft is presented on separate bobbins for insertion (Fig. 2.52).

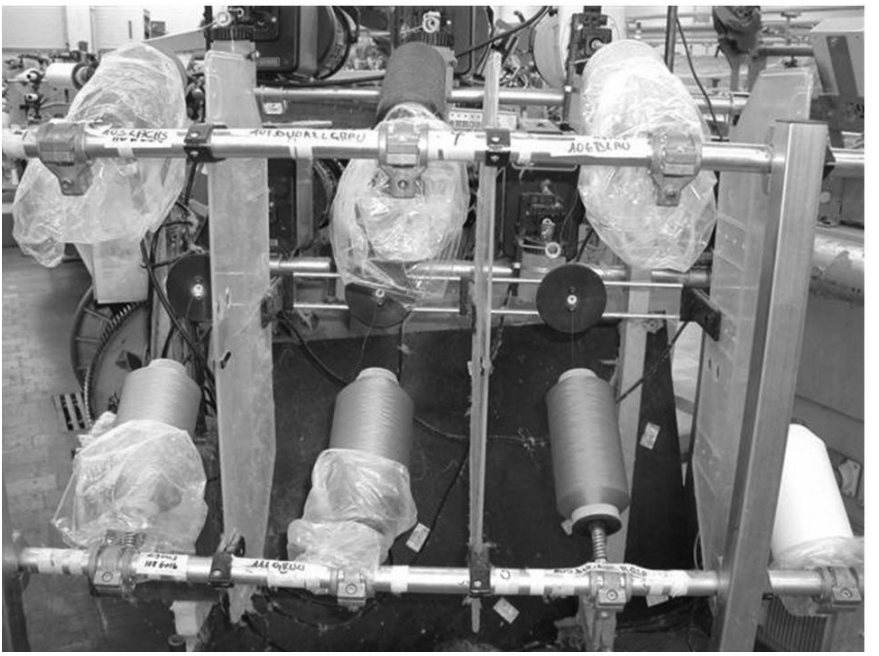
Fabric inspection

The third section includes inspection of the fabric that is carried out on illuminated tables, upon which the fabric is moved. Visual inspection is still best suited for detection of failures in the fabrics. There are some instruments



2.51 Airjet weaving technology.

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2.52 Insertion of different colored weft yarns.

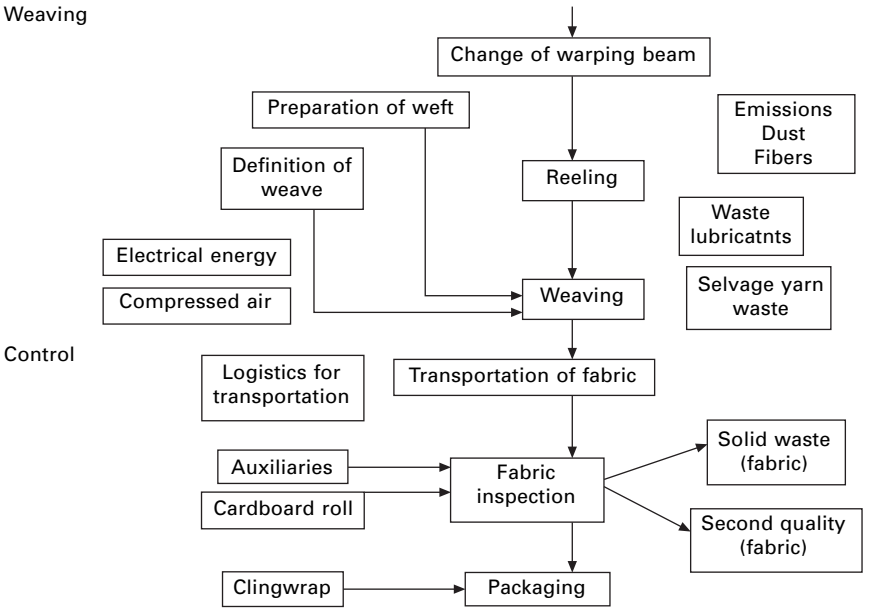
developed for automotive inspection; however, the many patterns in fabrics make it difficult to distinguish between fabric characteristics and failure. The processes for the weaving and inspection section are shown in Fig. 2.53. Some gray fabrics that need finishing are brought to the finishing department or plant, where the wet processing is performed, before the finished fabric is returned for final control.

Environmental indicators

On the input side electrical and fossil energy for the machinery account for the greatest impacts. The yarn for weft and warp quality and quantities have to be selected carefully for economic reasons. A number of materials for handling the yarns and products, such as bobbins, pallets and packaging material, have to be considered. Smaller amounts of laboratory chemicals, lubricants and oil as well as stain remover (in fabric inspection) are applied in the processes (see Table 2.10).

On the output side there is material and solid waste from logistics and maintenance, mainly for incineration but also for recycling (cardboard and textile waste). If the company applies sizing agent, there will be liquid waste of the agent for special treatment. The size is removed before bleaching and dyeing. Therefore, non-integrated mills cannot recycle sizing agent.

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2.53 Processes and material flows in the weaving department and in control.

Table 2.10 Environmental indicators in weaving

Inputs	Outputs
Raw material (kg)	
Weft yarn (different qualities)	Gray fabrics (m)
Warp yarn (different qualities)	Finished fabrics (m)
	Textile waste
Materials	
Bobbins	
Pallets	Pallets
Cardboard	Garbage
Packaging	Paper and cardboard (recycling)
Mechanical parts (replacement)	Metals (solid waste), electronic waste
Auxiliaries (kg or l)	
Sizing agent	Sizing agent (liquid waste)
Chemicals (laboratory)	Chemicals (liquid waste)
Lubricants and oil	Oil (liquid waste), effluents
Stain remover	
Energy	
Electrical energy	CO_2, NO_x, SO_2 (airborne emission)
Thermal energy	CO_2, NO_x, SO_2 (airborne emission)
Compressed air	Contaminated air

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Together with chemicals and oil, conventional effluents for treatment represent liquid output indicators. Logistics for finishing in commission call for additional transport and corresponding emissions.

2.6.2 Knitting and warp knitting

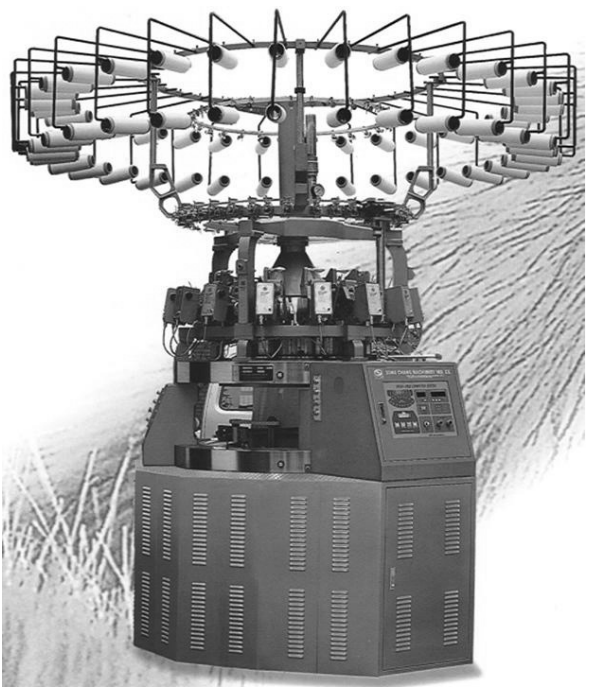
In machine knitting the traditional hand-knitting needles, holding all knits of a fabric, are replaced by individual needles for each loop.

Processes

The fabric consists of loops, which are interlinked, formed by means of needles. A high dimensional stability is achieved by this yarn orientation with flexibility in all directions. Most knitted fabrics are produced in the form of a tube on circular knitting machinery (Fig. 2.54).

Knitting

In the circular knitting process a number of yarns, coming from bobbins, sitting on a circle, are knitted simultaneously to the fabric. Similar to the



2.54 Circular knitting technology with 92 knitting systems.

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weaving preparation, the required number of bobbins has to be calculated and provided for the knitting system. The yarn bobbins should be conditioned for optimized running characteristics.

During the knitting process the fabric rotates, whereas the knitting systems are fixed on a cylinder. The fabric is produced with a multitude of knitting systems, each fed by a yarn bobbin. Machines with different diameters are available, each with a defined, fixed number of knitting sections. The systems are simultaneously knitting loops at a time. This means a knitting machine consisting of, e.g., 92 systems has 92 yarns running. If one bobbin is empty, it is replaced by knotting the yarns. The fast-running systems require considerable amounts of lubricants (needle oil) for perfect operation.

The knitting machinery stands preferably in an air-conditioned room. If different yarn colors or fiber types are applied within the production hall, each machine is separated by means of plastic covers in order to prevent foreign fibers from embedding into the knit.

Inspection and further operations

The gray fabric is optically checked for knitting failures and stains that can be removed. Failures are marked and call for a discount. Gray and colored knits are finished before the final inspection. Although knitted fabrics develop fewer wrinkles than woven fabrics, finishing operations like relaxation, washing, drying, fixation and wrinkle resistance improve fabric properties. Also the remainder of the applied needle oil (up to a third of the application) has to be removed in finishing.

Warp knitting

A special process is warp knitting, a combination of weaving and knitting technology. With luxury and elastic fabrics, warp knitting has become an important production technology. The fabrics are tulle, laces and fishnets, among others. The main applications are in sports- and swimwear, lingerie, embroidery and technical applications.

Similar to the woven fabric, it is based on warp. In the process of warp knitting all warp yarns are linked by stitches in the longitudinal direction. By this, each individual thread in the warp forms a wale. Innovations include the application of microfine and elastic yarns.

Environmental indicators

As for a weaving company, the main environmental impact in knitting companies is their use of energy. All impurities staying on the fabric are

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removed in pre-treatment processes of the subsequent finishing. Table 2.11 gives an overview of environmental indicators in knitting.

2.6.3 Non-wovens

Non-woven fabrics represent an increasing market in textile applications, e.g. for disposable wipes and baby diapers (see Table 2.12). According to Butler (2006), spun-laced technology has increased its market share, particularly in the USA.

The production can be described as follows. A web of natural and/or man-made fibers is prepared on a flat surface, whereby the individual fibers are oriented in all directions. Different bonding technologies and processes are applied such as:

- Creating physical tangles or tufts among fibers by stitching needles in place
- Application of adhesives
- Thermal fusing of fibers or filaments to each other by fusible fibers or powders
- Fusing the fibers by dissolving their surfaces.

Mainly man-made fibers such as PET, PP and rayon are used as fiber materials, but any fiber can be applied with the appropriate bonding technology.

Non-woven fabrics are applied only in selected apparel types like some sportswear or linings. The Association of Non Woven Industry (INDA) promotes this growing sector whose products are mainly domestically produced, due to their great mass. This represents a growing economic factor for many industrialized nations. If disposables are dumped in landfills, this cannot be considered as environmentally friendly.

Table 2.11 Environmental indicators in knitting

Inputs	Outputs
Yarns	Bobbins
	Yarn waste
Electrical energy	CO_2, NO_x, SO_2 (airborne emission)
Thermal energy	CO_2, NO_x, SO_2 (airborne emission)
Air	Contaminated air
Water	Effluents
Pallets	Pallets
Lubricants, oils	Oil contaminated fabrics
Mechanical parts (replacement)	Metals (needles, etc.)

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Table 2.12 Non-woven technology and products

Technology	Products/applications (disposables)	Products/applications (durables)
Carded thermal bonded and resin bonded staple	Cover stocks (greatest market), consumer wipes	Interlinings, interfacings, electronic components
Needle-punched staple fibers (carded)	Filtration media	Interlinings, interfacings (emerging), coated, laminated fabrics (upholstery, luggage, shoe components, wallets), bedding and home furnishings, automotive trim fabrics, geo-textiles, agricultural and landscape fabrics
Air laid	Absorbent media in sanitary napkins, consumer wipes, industrial wipes	
Wet laid	Medical surgical disposables (second market share), industrial wipes, filtration media	Electronic components (electrical isolation)
Melt blown	Sanitary napkins, incontinence products (PP), elastic side panels in training pants, medical/ surgical disposables (PET), consumer wipes, fabric softener (dryers), PET filtration media	
Spun-laced or hydro-entangled (carded, air laid and air entangled)	Medical/surgical disposables (PET), gloves, masks, sheets, pillowcases, consumer wipes (baby's) filtration media, industrial wipes, industrial protective apparel	
Laminates, combinations with film, foam, woven and knitted fabric		(Coated) apparel with special requirements
Porous films		Durable papers, electronic components

2.7 Chemical treatment

Chemical treatment is by far the most diversified process in the value-added chain of textiles. Processing is well described in Rouette (1995). Typically it is divided into three sections: pre-treatment, dyeing and finishing, of which

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the dyeing process traditionally is the most important. Dyeing plants are specialized in specific raw material processed as either yarn, fabric or apparel finishing. According to their specialization they have specific equipment for processing and they apply specific chemicals (from an almost infinite variety: Textilhilfsmittel Index 1994).

The finishing processes make large contributions to waste water, energy consumption and also airborne emissions. Traditionally, rivers colored by effluent were typical of finishing activities. In Eastern Europe and parts of Western Europe finishing departments are often integrated in weaving or knitting companies, sometimes even with spinning mills. Such integrated mills allow high efficiency in processing and optimization in product development. On the other hand they are often specialized on individual fibers like wool, cotton or linen. As fashion changes they risk a decrease in production if other fiber types are favored. In central Europe finishing is often carried out by subcontracting, whereby the finisher never owns the material but only adds value. Such companies may be better prepared for flexible specialization, but are less embedded in product development. Innovative finishers have to seek partnerships with weaving and knitting companies as well as with apparel manufacturers.

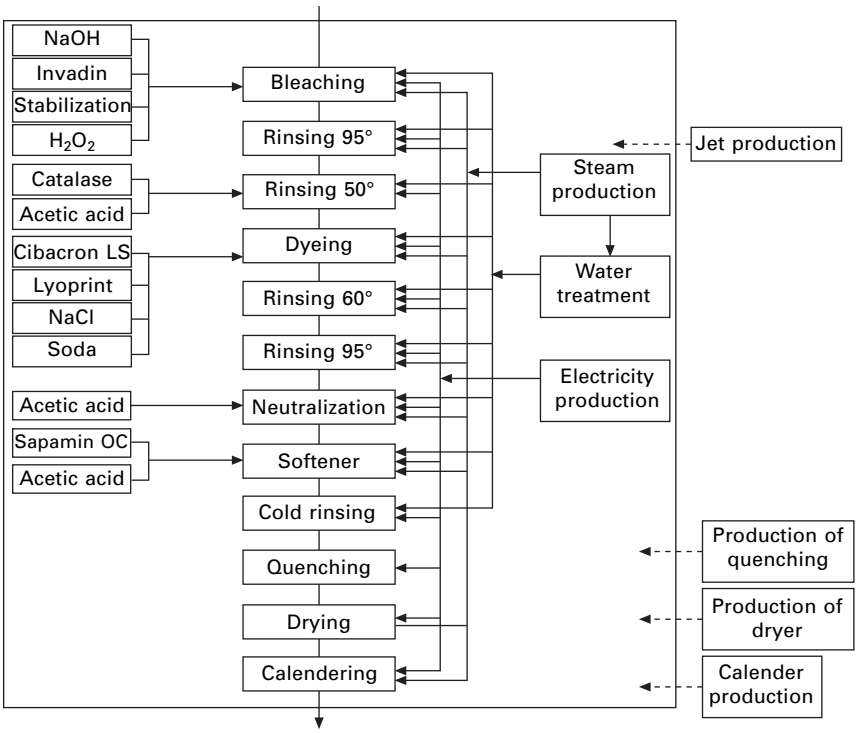
2.7.1 Processing

The following process definitions are generally given for cotton fabric, because they require the greatest variety in finishing processing. Process technology, formulas and individual agents have to be selected carefully for best results. Although process technology is addressed in Chapter 3, some main characterizations have to be explained in this chapter. Wet processing can be performed in two ways. First, in the exhaust process the fabric remains in a bath with agents for a defined time and at a defined temperature until saturation. The fixation in the exhaust process is time and temperature related. Alternatively, in pad technology the fabric is dumped in a highly concentrated bath, quenched and rolled. Fixation takes place in the roll, which is slowly rotated. Fabrics can be processed 'open' (in a pad system) or as a 'skein', as produced in circular knitting. Figure 2.55 gives an example of a formula for a cotton fabric.

Pre-treatment

Pre-treatment includes preparation processes of fabrics from individual fibers, especially for natural fibers, in order to reduce natural impurities and prepare the fabric for dyeing. The intended properties of the fabric are clearly defined, either as a requirement for further processing or as final properties:

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2.55 Finishing processes with inputs in the pre-treatment, dyeing and finishing sections for a cotton fabric (source: Zwicker 1997).

- Aimed properties:
 - Regularity
 - Free of foreign matter
 - Hydrophilic (for absorbance)
 - Luster
 - High whiteness
- Processes:
 - Singeing (cotton)
 - Desizing (mainly natural fibers)
 - Carbonizing (wool)
 - Scouring (cotton)
 - Mercerizing (cotton)
 - Bleaching (mainly natural fibers).

In the tradition of textile finishing these individual processes and process technologies have been developed as follows and are outlined in Chapter 3. New (man-made) fibers and today's time efficiency are leading more and more towards fewer processes or combined processing.

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Singeing

In singeing, the hairy surface of cotton fabrics is smoothed and equalized through treatment with a gas flame on both sides of the fabric. The fabric is transported an appropriate distance to the flame equipment in order to prevent it from burning.

Desizing and scouring

Most cotton fabrics and some microfiber fabrics (PES) are sized for improved mechanical processing in weaving. The sizing agent has to be removed by means of a desizing agent. Even small residues of the sizing agent could interfere with chemicals from subsequent finishing processes, particularly in dyestuff uptake of the fabric. For removal of impurities, cotton and other natural fibers are scoured in a vessel with caustic soda, at high temperature and under pressure. A similar process at ambient pressure is defined as boiling.

Bleaching

The original yellowish-beige color of natural fibers is eliminated in the bleaching process. Several bleaching agents are available and are applied according to the fiber type and the color finally desired.

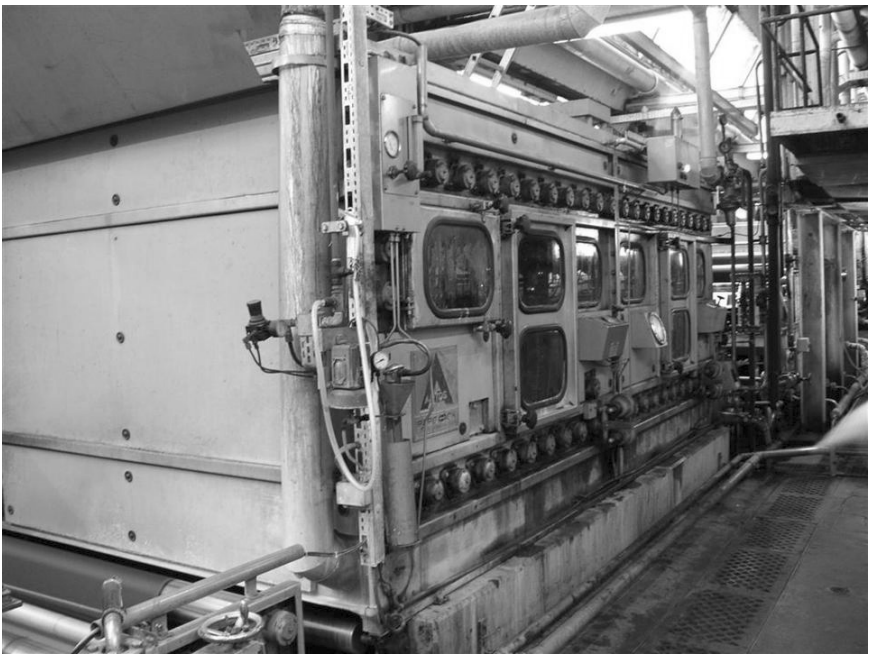
Mercerizing

Cotton fibers develop a luster if treated with alkali (mainly caustic soda, rarely ammonia) through liquid uptake and fiber swelling. In the mercerizing process the treatment is combined with tension of the fabric (on a stenter). Alkaline treatment produces a somewhat lower luster and is processed without tension. High quality cotton, particularly for knitting yarns, is often mercerized.

Washing

In washing processes, as sub-processes of the main pre-treatment, dyeing and finishing processes, the fabric is moved through a machine that consists of several chambers. Each chamber is individually supplied with water, agents and auxiliaries. After a defined number of cycles, the fabric is quenched and the surplus solution flows back to the chamber. Generally the washing water is reused and circulates in counter-current flow. In product lines with exhaust technology the washing process follows continuously from the previous stage (see Fig. 2.56).

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2.56 Continuous processing machine (source: Ackermann and Bernasconi 2005).

Drying

After the last rinsing process the fabric is finally quenched and transported into a tunnel dryer, where several heating zones process the slowly and tensionless moving fabric.

Dyeing and printing

The dyeing and printing processes are specifically adapted to the type of fiber.

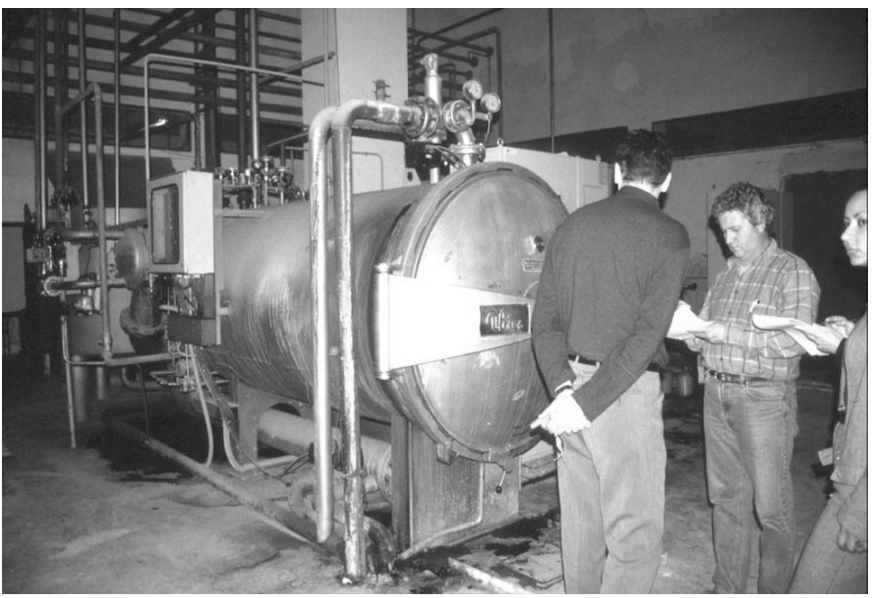
Dyeing

In the dyeing process the fabric is given the desired color with defined requirements considering color fastness (see Fig. 2.57). The principle follows the sub-processes of application, fixation, rinsing and washing, whereby different technologies are applied (outlined in Chapter 3). Figure 2.58 shows an example of exhaust dyeing in a jet. The fabric is exposed to the appropriate dyestuff, whereby different auxiliaries are added according to the chosen technology. A high exhaustion degree is aimed at in order to

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Aims:	Color Equality Permanence Reproducibility
Principles:	Application Fixation Rinsing and washing
Requirements (ecology):	High exhaustion degree Low COD (chemical oxygen demand) NO AOX (chlorinated organic hydrocarbons)

2.57 Aims, principles and ecological requirements for dyeing processes.



2.58 Jet dyeing machine for dyeing processes in exhaustion technology.

reduce environmental impacts of the effluent. After fixation, excess dyestuff is washed off with laundry agent and other additives like acetic acid for neutralization.

Printing

Printing is a surface treatment with color pigments, meaning the fabric is provided with a color pattern on one side. Unlike in dyeing, color uptake throughout is not aimed at. Moreover, a clear distinction between the different color areas of the pattern has to be achieved. Pigments are fixed in defined

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positions by means of a glue-like substance. The main agent is the print paste, consisting of the color pigment, auxiliary and water. A thickener (often an alginate) helps to locate the pigment precisely on the substrate. After application the fabric is dried for fixation of the pigments, rinsed and washed with addition of acetic acid and dried.

Finishing

In the third process section, called finishing, the surface properties of the fabrics are formed. The basic aim is to achieve dimensional stability of the fabric and to regain the natural soft touch that was lost in processing. Additionally the 'make-up' of the surface is constructed according to specific requirements (see Section 2.7.2).

Dimensional stability

The basic requirement for a fabric is dimensional stability after washing. The fabric is artificially compacted in order to prevent it from shrinking in the washing process of the consumer. The fabric is fixed on both sides on a system of chains and compressed in the length dimension. In this condition it is dried, whereby the shrunken position is fixed (see Fig. 2.59).



2.59 Shrinkage of fabric for dimensional stability.

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Softening

In finishing processes, cotton fibers lose all their inherent waxes and oils that would give a fabric a soft touch. The fibers become harsh. With addition of softeners (permanent or soluble) the surface properties are rebuilt to a desired degree for feelings of comfort.

2.7.2 Specific requirements of the market

A number of properties have to be applied to fabrics for consumer satisfaction and comfort:

- Soft touch
- Drape of the fabric
- Wrinkle resistance (no ironing)
- Care properties (wash and wear, fastness)
- Low shrinkage (dimensional stability)
- Water repellency
- Mud repellency
- No harmful substances
- Antistatic
- UV protection
- Anti-felting
- Anti-microbial
- EMC shielding
- Flame retardancy.

It is open to discussion as to how many of these properties are really a 'need' from the consumer's side and how much is promoted by the markets to increase turnover (see also Chapter 5). While fashion (color and surface characteristics) is a conventional requirement, more and more special care properties become important. Selected properties are desired for special applications in sportswear and protective clothing.

Fashion

The most prominent effect in apparel fashion has been and will always be style and color. The selection for a season is made at well-known fashion shows in New York, Milan, London and Paris. Fashion stylists set colors and trends for new fabrics long before they are presented in shows. Apparel manufacturers can get actual trends also from fashion stylist networks via the Internet. This input goes to fabric design, including information on drape, hand, color and 'make-up' of the fabric. The selection of fiber types and weaves or knits is made for weaving or knitting, and the fabric is produced

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accordingly. Color and surface properties are set in finishing. Favored colors may alternate between light, deep, dull and brilliant, which requires appropriate selection of dyestuffs, while optical surface properties often require printing or chemical and mechanical treatment. Often innovative processes, like for instance pattern creation with selective removal of specific fibers, are developed in cooperation with finishers.

Care properties

Today's consumers prefer apparel that is easy to care for. They prefer good color fastness, requiring less sorting for laundry, no ironing to save time, and fast drying properties, allowing fast availability. The trend goes towards a simplified procedure with no loss of properties (see also Section 5.5, 'Consumers preferences', in Chapter 5). Consequently these desired care properties have to be set during finishing. This requires specific processes to set dimensional stability, but also the use of appropriate dyestuffs for good values in color fastness (towards light, seawater, sweat, or migration of dyestuff to other fibers, etc. – see above).

Additionally, more and more fabrics provide wrinkle-resistant, water-repellent and oil-repellent properties, which are achieved by means of special finishing treatment. All these characteristics are measured and checked by standardized tests[13] (see Chapter 3). Finishing processes build up properties for easy care. Generally they consist of three steps. First, the fabric is exposed to an impregnation liquid, whose crosslinking molecules react with the fibers of the fabric, if exposed to high temperatures. Fabrics can be impregnated on a pad system or in exhaust technology, after which excess liquid is quenched. Subsequently, the flat fabric is dried on a stenter. In condensation, the third step, the crosslinking fixation takes place, with higher temperatures than in the previous step. Processing is often associated with additional environmental impacts through resins and/or organic solvents in effluents or airborne emissions.

Special properties

The distinction between care properties and special properties is not precise. Consumers prefer apparel with a soft touch and fall, particularly for underwear and apparel with skin contact. Softeners, mainly consisting of lubricants and resins, are applied in wet processes, followed by drying. Such wet processes produce contaminated effluents with high persistence against degradation as well as airborne emissions. Harsh or stiff fabrics are outlawed, except

[13] ISO, EN, SN, DIN, JIS, AS/NZS, AATCC, ASTM, BISFA, IWTO, Marks & Spencer, Tchibo, TEGEWA, ICI, EMPA.

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for some desired fashion trends. Finishing with a more or less permanent softener may not be considered as a special property, but flame retardancy, protection against UV radiation and antibacterial finishing certainly are. Antibacterial treatment mainly consists of silver, triclosan or chiton as active component. Triclosan[14] is preferred due to its properties: no skin irritation, no mutagenic, carcinogenic or toxic effects, and no bioaccumulation. It is applied in solution and exhausted to up to 100% by the fiber. The small quantities that are ejected to the effluent are degraded in the sewage plant up to 95%; the rest is degraded by UV radiation.

UV protection is achieved by specific dyestuffs, active in the non-visible UV wavelengths.[15] The degradation follows the dyestuff treatment with the advantage of no color. For effective flame retardancy often specific fibers are used, but also specified chemicals can be applied as well. Some nations have implemented legal requirements on flame retardancy properties in babies' and children's wear as well as for home textiles in public buildings. Protection against UV radiation is more important for children's wear, as children take up about 80% of the lifetime radiation until the age of 20.[16] The southern hemisphere is particularly affected due to the reduced ozone layer in the stratosphere. Even if these requirements are not given for all nations, the trend in a global market will go towards standardized products with such properties. Antibacterial finishing is certainly appropriate for sportswear with extreme demands, but may also become a fashion for less strenuous sports to provide users with some 'excellence'. Consequently, finishing processes will increase in environmental impact, due to the specific chemicals applied.

2.7.3 The position in the value-added chain

The finishing processes, particularly dyeing processes, can be carried out with fibers, yarns, fabrics and pieces, whereby different technology, equipment and processes are applied. The selection of such finishing types is determined by the raw material, the quality and the end use of the product. The earlier the finishing is carried out, the more limited is the material to specific applications. The choice of an early dyeing process makes the product generally more expensive, due to later losses of material in yarn and fabric production. But some raw materials, especially some natural fibers, require a pre-treatment in the first process steps because certain properties have to be fixed before further processing. Cotton, linen, flax and hemp are mainly finished as

[14] Trichlorophenoxyphenol: $C_{12}H_{10}O_2Cl_3$.
[15] Specific dense fabric construction also contributes to UV protection.
[16] Campaign Krebsiga Schweiz.

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'one color fabric' for apparel like jeans, skirts, shirts and blouses, or as multicolored printed apparel like blouses and shirts. Man-made cellulosic fibers like viscose, rayon, Lyocell®, Meryll®, etc., can be treated in the same way. Colored knits and colored woven fabrics with patterns require colored yarns. Consequently these value-added products are more expensive due to the combination of sophisticated knitting or weaving, combined with yarn dyeing. In most cases additional finishing of the fabric for specific properties is carried out subsequently. If blended yarns are constructed, also dyeing of fibers (flocks) is carried out. Wool must be pre-treated as a fiber for fixing dimensional stability. Wool is often also fiber-dyed or yarn-dyed for high quality fabrics with patterns. Specific properties may be applied to the fiber or in a second finishing to the woven or knitted fabric. Very similar is the processing of silk finishing, whereby the natural, reeled silk filament is dyed, and weight is added to allow better processing in weaving or knitting. Also silk fabrics are finished for desired properties.

The chemical fibers polyester, polypropylene and polyacrylic can be produced in spun-dyed quality, although polyester is mainly dyed as a fabric, again depending on the fabric quality. Spin dyeing is carried out where considerable amounts of yarns or limited variations of colors are produced.

2.7.4 Environmental impacts and indicators

Environmental impacts in textile finishing were always associated with waste water parameters and treatment. Obviously there are the colored effluents, but the invisible substances are often more toxic than the dissolved dyestuff. Today we also face airborne emissions (CO_2, NO_x, SO_2) caused by energy production (steam) and by special finishing processes (see Table 2.13).

Generally the effluents are ejected to a waste water system heading to the waste water treatment plants of a community. There the conventional waste water parameters are measured as follows. The 'biological oxygen demand' (BOD) is a measure for biological degradation of the effluent and indicates the consumption of oxygen by bacteria, which is necessary for the degradation processes. The reaction time is set by 5 days and declared as BOD_5. The 'chemical oxygen demand' (COD) is measured by means of standardized OECD guidelines, whereby the amount of oxidant (dichromate or potassium dichromate) is determined and calculated in oxygen. 'Total organic content' (TOC) includes all carbon content in organic molecules. 'Dissolved organic carbon' (DOC) is defined as the amount of TOC that is not filtered by a membrane with 0.45 μm porous. If the load of finishing companies exceeds by far the capacity of the municipal plant, additional treatment on site becomes necessary (see Chapter 3).

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Table 2.13 Environmental indicators in finishing

Inputs	Outputs	Waste water parameters
Pre-treatment		
Caustic soda	Caustic soda	pH
Peroxide		
Water		
Air		
Electrical energy	CO_2, NO_x, SO_2 (airborne emission)	
Thermal energy	Excess heat	
Stabilizing agents	Stabilizing agent	
	Organic waste (pectins, natural waxes and oils, insects, minerals)	TOC, COD, BOD, K
	Agrochemicals (pesticides, defoliant)	
	Paraffin and knitting oils	
	Heavy metals	Heavy metals
Dyeing and printing		
Salt	Salt	Conductivity
Dyestuffs	Solid waste (dyestuffs)	
Tensides	Tensides, detergents	
Auxiliaries, acids	Chemicals (VOC, AO_x (airborne emission))	pH, heavy metals, P, SO_2, K
Water	Waste water (oils and filtered particles, dyestuffs)	TOC, DOC, BOD, COD
Thermal energy	CO_2, NO_x, SO_2 (airborne emission)	
Electrical energy	CO_2, NO_x, SO_2 (airborne emission)	
Bonding agent	Liquid waste	N
Finishing		
Resins	Solid waste (filters)	N, TOC, DOC, BOD, COD
Catalysts	Waste water	Heavy metals
Enzymes		TOC, DOC, BOD, COD
Softener	Airborne emissions	
Tensides		
Auxiliaries		
Thermal energy	CO_2, NO_x, SO_2 (airborne emission)	
Electrical energy	CO_2, NO_x, SO_2 (airborne emission)	

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2.8 Manufacturing

In apparel design a three-dimensional product is constructed by assembling different flat pieces of fabric. Fashion (see Chapter 3) creates ideas about shapes and styles that could be implemented, whereby the shape does not necessarily follow the body line. If the fabric for a designed apparel is chosen, the style, cut and three-dimensional shaping is constructed by means of a sewing pattern. For every model a list of all accessories (thread, lining, stiffening material, zippers, buttons, snaps, lining pads, fixing parts, etc.) is compiled and detailed instructions for the step-by-step sewing are generated, including specifications about stitches and other machinery settings. The more complex and sophisticated these instructions are, the more expensive the apparel becomes.

In the grading process, designed with computer software, a prototype pattern is transferred into different sizes by adjusting the individual parts in appropriate dimensions. Human body size, however, shows a large variation: the differences are often not proportional, and many genetic and cultural specialties exist. The procedure is far from being standardized (see the section on style in Chapter 5). This makes the fit of apparel so difficult.

After the sized patterns are constructed, they are arranged on the fabric in such a way as to produce a minimum of waste. Fabrics with pattern require additional adjustment for the parts to be cut for matching of the parts in the final apparel. Some hairy fabrics, like velvet or 'Manchester', etc., show a prominent up–down orientation in the brush, or other structures influencing the light reflectance, which requires a consequent orientation of the pattern parts according to the fabric orientation. Marks are applied with the cutting auxiliary for assembling the different parts of an apparel.

Together with the cut parts for a piece, accessory material is assembled for further processing. On various sewing stations the apparel is produced according to sewing instructions, step by step. For correct assembly, the auxiliary marks of the pieces have to be arranged before the pieces are sewn. Some of the sewing stations carry out very simple processes, while other stations are highly specialized for specific processes like fixing a zipper, inserting pockets, sewing buttonholes, etc. The manufacture of men's jackets may follow the most complex guidelines, while sewing a knitted T-shirt is an easy assembly with not more than 10 individual steps.

Manufacturing is the most labor-intensive stage in the production of apparel and therefore one of the most costly parts in the value-added chain. Many companies seek production sites in countries where employees work for low salaries but have good working skills. Worldwide, sewing is carried out mainly by women on traditionally lower salaries than men's (see the section on sourcing in Chapter 5).

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2.9 Consumption, use and care

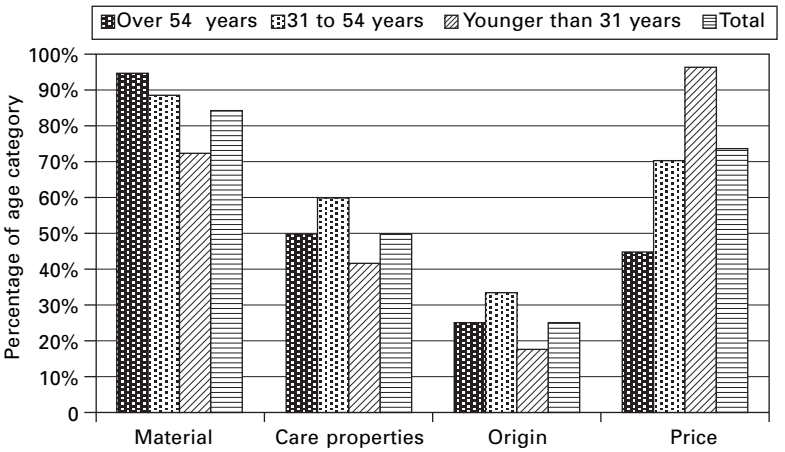
Consumption, use and care patterns are different for individual cultures. In this section results of representative case studies in Switzerland are outlined. They can serve as examples of average practice in central Europe. The consumption patterns are expressed differently in the Nordic countries, where protection of the environment is even more advanced, as a result of increased awareness and political tendencies (see also Chapter 1). Southern European countries have only recently developed stringent environmental legislation and are fast catching up. Consumption is also addressed in Chapter 5, where the USA and EU are discussed.

2.9.1 Consumption and use

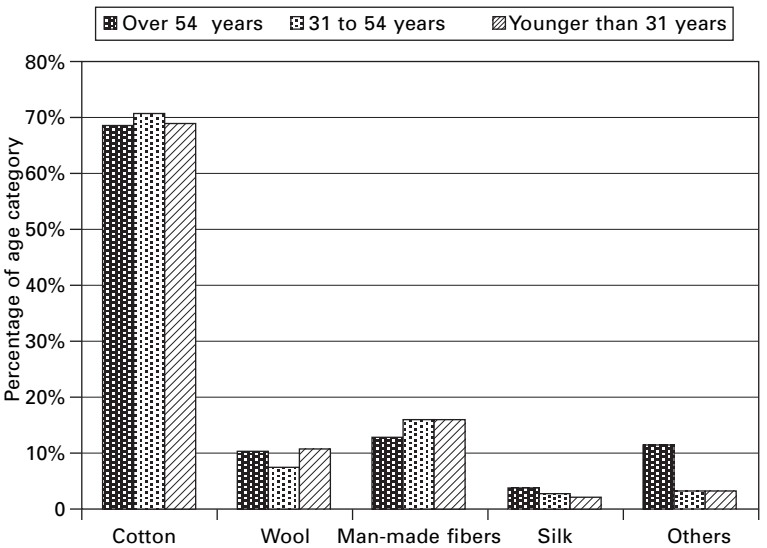
Consumption of apparel has far exceeded basic needs in industrialized countries. Consumers are buying apparel no longer only for thermal protection, but for identification with a unique style to underline their individualism. Apparel is not used until its 'technical' end of life is achieved, but thrown away when the consumer wants new apparel, driven by the fashion market. This lifetime duration is defined as the 'economic' lifetime compared to the technical lifetime, which generally is significantly longer than the economic lifetime. For greater sustainability, this could be adjusted in two ways: either society changes towards more sustainable consumption in wearing apparel until it is more worn out (a not very feasible option on short-term considerations) or the technical lifetime is shortened to match more closely the economic lifetime (a trend already seen with some apparel producers). For the customer's choice, a definition of cycles or a yarn count (as applied for bed sheeting in the USA) could be defined by the manufacturer. In a case study (Affolter and Steiner 2002) with limited significance, the question for general criteria in purchasing was investigated in Switzerland (see Fig. 2.60). For economic reasons a younger generation is more interested in price than in material of apparel. These different results for different ages represent a trend and are in accordance with larger studies from professional institutions (AISE 2001).

The study also revealed the preferred material of the different groups (Fig. 2.61). When discussing the result of the high preference of cotton, one must assume that particularly younger and male consumers do not have sufficient knowledge about fiber material. The study was carried out in 2002 and the ratio of man-made fibers to cotton may have changed since then (see also Chapter 5).

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2.60 Criteria for purchase: material, price, origin (where made), care properties.



2.61 Preferred materials for apparel: cotton, man-made fibers, wool, silk.

2.9.2 Care

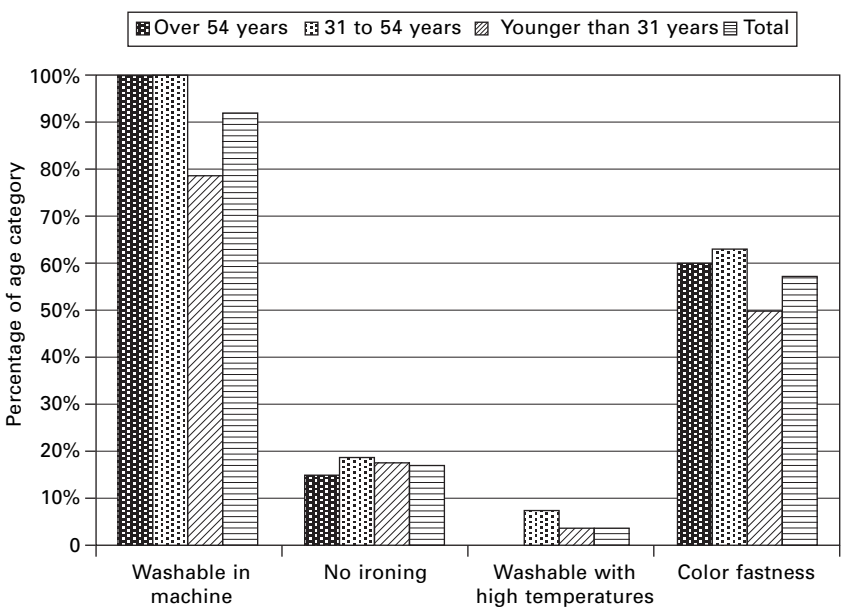
Care is the action in use that produces environmental impacts. It it based on consumer preferences for care properties, combined with the laundry processes for apparel.

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Consumer preferences

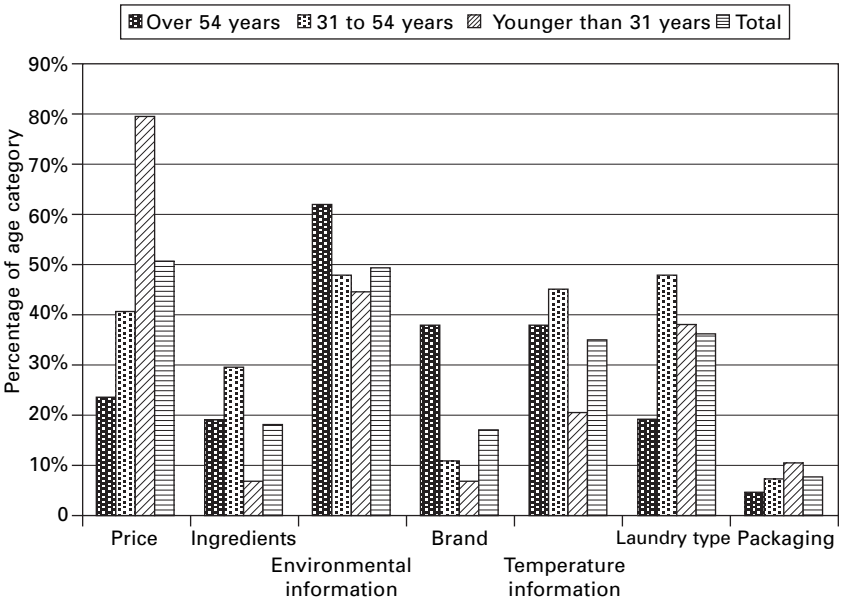
The study investigated consumer requirements for apparel care (Fig. 2.62). Older generations have a definite preference for washable apparel and color fastness, categories which are less important for the youngest generation. The properties of wrinkle resistance and washability of high temperatures are also less important.

Criteria for purchase of laundry agent are given in Fig. 2.63 (Affolter and Steiner 2002). As all categories had been offered for priority selling, the results may perhaps represent what people intend to apply. They give the following ranking: price, environment, washing temperature, type (liquid, compact, etc.), ingredients, brand, and packaging. In this ranking the position of 'environment' seems to be overestimated, while the packaging is underestimated. Affolter and Steiner (2002) analyzed trends in consumption in Switzerland and the EU, based on Grieshammer *et al*. (1997) and a survey called the Trend Study (Table 2.14). The results concerning preferred washing temperature are in good accordance, while the preference for a compact laundry formula was much higher in the AISE (2001) study. Consumption of laundry agent per person was significantly lower in the Trend Study.



2.62 Requirements for care properties; machine laundry, color fastness, wrinkle resistance, high temperatures.

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2.63 Laundry agent: price, environment, washing temperature, type (liquid, compact, etc.), ingredients, brand, packaging.

Table 2.14 Comparison of EU and Swiss preferences in laundry

Preferred washing temperature			
	90°C	60°C	40°C
AISE study (1997)	6%	36%	48%
Trend Study (2002)	6%	30%	45%
Laundry agent type			
	Compact	Traditional	Liquid
AISE study (1997)	49%	31%	20%
Trend Study (2002)	32%	47%	22%
Consumption (kg/person and year)			
AISE study (2000)		9.39	
Trend Study (2002)		4.77	
Switzerland (2000)		8.26	

Laundry ingredients

Laundry agents consist of groups of ingredients, depending on the specialization for washing temperature, fiber material and color as well as formulation (powder, liquid or compact granulates). The main parts of laundry agents are tensides, builders and bleaching agent.

Tensides comprise the washing-active group in the laundry agent with a combination of lipophilic and hydrophilic chains in a molecule. With this

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polar structure they reduce the surface tension of the water, allow the water to penetrate the yarn and fabric (hydrophilic chain) and dissolve dirt particles (lipophilic chain). In the form of an emulsion these particles can be removed from the textile with the effluent. According to the electric charge of the molecule, tensides are either anionic (LAS), non-ionic (AE), or cationic.

The function of **builder** substances is to support the washing-active tensides by linkage with calcium and magnesium ions from water and particles.

Impurities which cannot be removed by washing are discolored with oxygen by chemical **bleaching**. The most common bleaching agent is sodium perborate, offering good efficiency for temperatures higher than 60°C. It can be activated also for lower temperatures in association with tetra-acetylethylene-diamine (TAED). Perborate reacts to natural minerals with no harm to the environment.

Other auxiliaries are applied in small quantities to laundry agents but provide properties that are essential for modern laundry:

- **Optical brighteners** react like dyestuffs with fluorescent properties. When attached to the fiber they produce a whitening effect not by bleaching but by coloring.
- **Graying inhibitors** stick to dirt particles and prevent them from attaching to the fiber.
- Impurities of proteins and fats can be dissolved by **enzymatic treatment**.
- Increased foam build-up may lead to overflow of the laundry agent in the drum and a considerable loss of active substances for the process. Additionally the mechanical treatment of the laundry is reduced. **Foam regulators** help to control the process.
- **Corrosion inhibitors** prevent corrosive impacts of the laundry agent on the laundry machinery (especially aluminum parts).
- **Perfumes** provide the laundry with an appealing aroma by covering the alkaline smell.
- **Suspending agents** are used as auxiliaries for good trickle properties of the laundry agent, which enable precise dosage in application.

Professional laundry and private laundry

The difference between private and professional laundry is evident on one hand by the requirements for the laundry type and on the other hand by the equipment, supply processes and laundry agents. Professional laundry is required by hospitals or industry for cleanliness of the textiles: from non-bacterial to sterile up to more stringent medical requirements in hospitals, but also for employees' work safety in companies. Consequently the spectrum goes from ordinary laundry to the most sophisticated laundry processes. For

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economic reasons the laundry is moved through different compartments of a laundry machine (see Chapter 3) and the process water is reused (see the section on finishing in Section 2.7.1). Laundry agents are designed to fulfill the cleanliness requirements and are applied at appropriate dosages, also in relation to the water hardness. Specific supply processes for sterilized water and steam production are established as well. A well-defined logistic for textiles supports easy and economic handling.

Machines for private (domestic) laundry consist of a rotating drum in which the laundry remains during all processes, while water and agents are added and ejected. This system requires more water than the professional machinery with several chambers. Moreover, many users do not know the hardness of their water supply and generally use more laundry agent than necessary. The application of fabric softeners for a feeling of comfort and a sweeter smell has spawned a huge market for entirely comfort reasons with no necessity from a cleanliness point of view.

Drying operations in professional laundry are performed in highly efficient systems for large quantities, compared to the less efficient tumble drying and ironing in private households. However, there is the option of using a clothes line in private households: time consuming but energy saving, as most pieces can be folded easily without ironing. An interesting option is also given by wrinkle-resistant finishing, though the generally lower lifetime of such apparel has to be taken into account.

Environmental indicators in care

Environmentally conscious consumers are often tempted to judge textile production processes very harshly as environmentally polluting. We often forget that we can directly influence much of the environmental performance of textiles by applying careful practices in the use phase. Table 2.15 summarizes results and consequences of the care activities in central Europe.

2.10 Disposal, reuse and recycling scenarios

This section defines some strategic considerations. A representative case study on textile recycling systems will be presented and the results of two case studies will be given on material flow – for polyester and polyamide, both carried out in Switzerland.

2.10.1 Strategic considerations and practices

Recycling/reuse options

Different qualities in terms of material and environmental impacts can be achieved by different technologies. Original recycling provides the same quality

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Table 12.15 Environmental impacts in the use phase

Relevant factors	Characterization
Laundry agent (ingredients)	Washing agents became more environmentally friendly during the last 5–10 years. Swiss legislation of 1986 prohibiting agents containing phosphates improved water quality considerably. So-called full washing agents contain optical brightener and bleaching agent, both very persistent in water (Pulli 1997). Combination of washing agents reduces impacts. Ingredients like Moshus-Xylole are prohibited in Western Europe (Saouter and van Hoof 2002).
Amount per dosage	Most people tend to use higher dosages than required. Adjustment to water quality (Ca^{-} content) is still mostly lacking. The Swiss apply 8.4 kg washing agent per person and 3.4 kg auxiliaries per person.
Type of laundry agent	Compact washing agents have proven high efficiency, but older people still prefer traditional types.
Washing machines	Water consumption as well as energy consumption are high, depending on water temperature (Rohr 2003, Affolter and Steiner 2002). Energy labels give information about consumption.
Color fastness	Sorting out of colors leads to low quantities per process using the same amount of water and energy if no adaptation of washing quantity is offered by the machine.
Washing behavior	People wash more frequently and in small households machines are used for small quantities, increasing consumption of water and energy.
Drying	Tumble drying requires additional energy. However, many apartment facilities do not offer opportunities for drying in the fresh air. Working people do not have time to spend on labor-intensive procedures.
Ironing	Ironing requires high amounts of energy (Pulli 1997). Wrinke-free fabrics have a shorter life cycle, due to damage caused by the finishing process, if yarn quality is not adjusted.
Fiber and fabric types	Most cotton fabrics (blankets, towels and clothing) are washed at higher temperatures (60° or 95°C). The shift to man-made fibers leads to lower washing temperatures and lower energy consumption. However, health and hygiene aspects have to be considered if underwear and socks are washed at low temperature as development of microorganisms is favored. On the other hand, man-made fibers produce less wrinkling and need less ironing. Wool and silk require low temperatures and soft agitation.

as is produced by the original resource. There are two ways to 'downcycle' where inferior quality of the material can be expected. Downcycling means processing material for a second use phase in a product of lower quality.

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Typically the products manufactured by this secondary resource are not the same, because the quality of the material has declined due to the loss of properties during the recycling process. Thermal recycling, use of the original fossil compound as heating material, is also considered as downcycling.

Very often the technical lifetime is not over when apparel are disposed of, meaning that the economic lifetime is shorter than the technical. A second use phase can be added if apparel are sold in secondhand shops or collected in a community waste management system and shipped to developing countries for reuse.

Recycling practices

Recycling concepts of a society are designed according to the political situation, which should include technical feasibility. Historically, every nation in Europe has developed its own recycling concept. This is particularly the case for textiles and apparel. As they are not considered to be harmful goods but to have reuse options, they are collected in separate activities or disposed of with municipal waste. The systems for collection have developed independently with individual recycling fractions. However, the EU has addressed specific recycling fractions with certain Directives, such as for waste of electrical and electronic equipment (WEEE). In the l990s a similar collection system was discussed for textiles. Some companies developed concepts for collection systems and reuse of material. The USA sends large quantities of used apparel to developing countries, mainly in Africa, where a new secondhand market sector for fashion apparel has been opened, known as 'matumba' (Rivoli 2006).

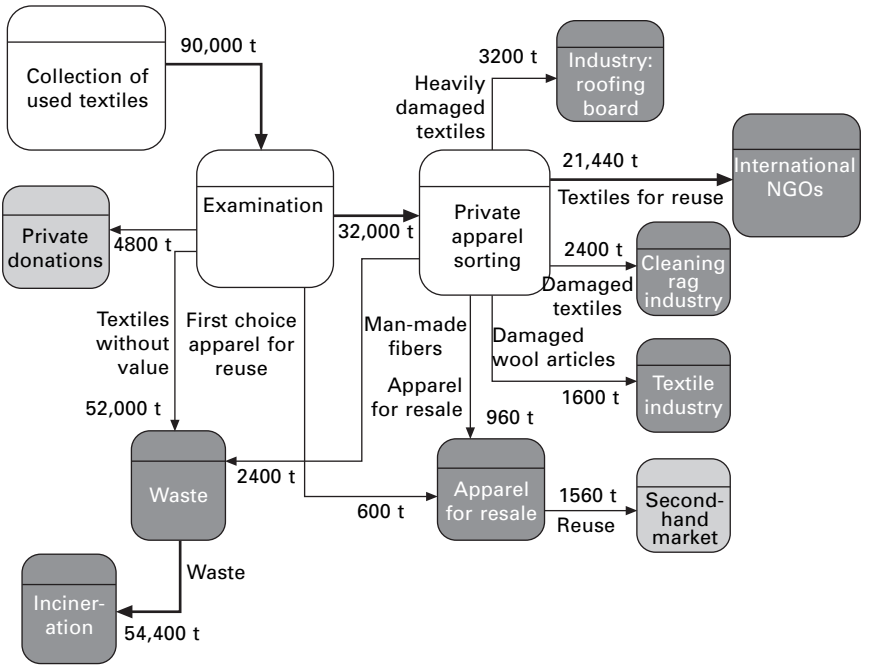
Material flows of specific textile materials are not easy to follow, because they are based on commercial relations. A specific situation is given below in Switzerland, where Customs report on imports and exports.

2.10.2 The Swiss recycling system

Textiles and apparel may be added to the municipal waste, which is collected weekly by the communities from every household in recycling bags upon payment of a fee. The collected mixed household waste is incinerated in incineration plants with defined filtering processes and limits on the emissions. The resulting slag shows by legislation the properties of natural rock and stone, because all harmful substances are concentrated in the filter ashes, which have to be disposed of under specific safety requirements. By this system 62% of all used textiles are disposed of and thereby contribute to the energy content of thermal recycling.

Private companies like TEXAID, Contex and Texta have established logistics for collection, transportation and sorting (see Fig. 2.64), aiming at

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2.64 Material flows and processes applied in apparel recycling (Swiss case study).

a high quota for reuse. For collection, two logistical systems are applied: by two annual collection tours to every household, where specific apparel bags are placed on the street or by collection containers that are placed in the communities. The latter seems to be favored as experiences of TEXAID in recent years have shown. In sorting of textiles, quality and material aspects are considered before the apparel is sorted into one of the four main categories: apparel for reuse (68%) for resale (3%), for downcycling as damaged textiles (22%) and waste (7%). The largest category is 'apparel for reuse' with nearly 70% of the collected clothing representing 22,400 tons a year out of a total of 32,000 tons (Maechler *et al.* 2004). Apparel for reuse is sorted into secondhand, to be sold in Eastern Europe, and for NGOs. From the relatively small amount of secondhand (960 tons) the organization is financed. The balance of 21,440 tons is sent for distribution to NGOs to deliver to the working poor in developing countries. Within the downcycled, damaged textiles the sorting follows the criteria 'heavily damaged', 'damaged' and 'damaged wool', according to the requirements of the market.

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2.10.3 Case studies: recycling PET and polyamide

PET recycling idea of Ecolog®

Original (chemical) recycling

Only products made of man-made fibers like PET or PA can be originally recycled, if they are collected as genuine and sorted according to color. The preparation of the used material includes sorting, removal of metallic parts, rinsing, filtration, crystallization and drying processes. The removal of the spinning preparation can be achieved by processing in an extruder with two degassing zones.

The polymerized fibers are processed down to monomers and repolymerized. Three options are available for depolymerization:

- Hydrolysis to TPA or DMT
- Alcoholysis of DMT by means of glycolysis or methanolysis
- Depolymerization by means of glycol and re-estering.

Any additives for processing or protection properties can prove to have an impact on the new polymerized fiber. Purification processes are mainly too costly. Often a certain percentage of recycled material (5%) can be added without any losses in quality (Mathieu 2003).

Mechanical recycling

Depending on the granulation properties of the apparel or textile waste, compacting or shredding is applied. Every process first requires removal of any metallic parts. Granulation is only feasible with sorted compact material, which is milled to granulate of 3–6 mm. Fiber waste (yarn, fabrics of PET, etc.) for compacting are cut and fed into a compactor where they are reprocessed by means of compaction and heating to the optimum plasticization temperature, cooled, and milled. This system has been applied in the case study by Ecolog® with the aim of producing melt-spun products (see Fig. 2.65).

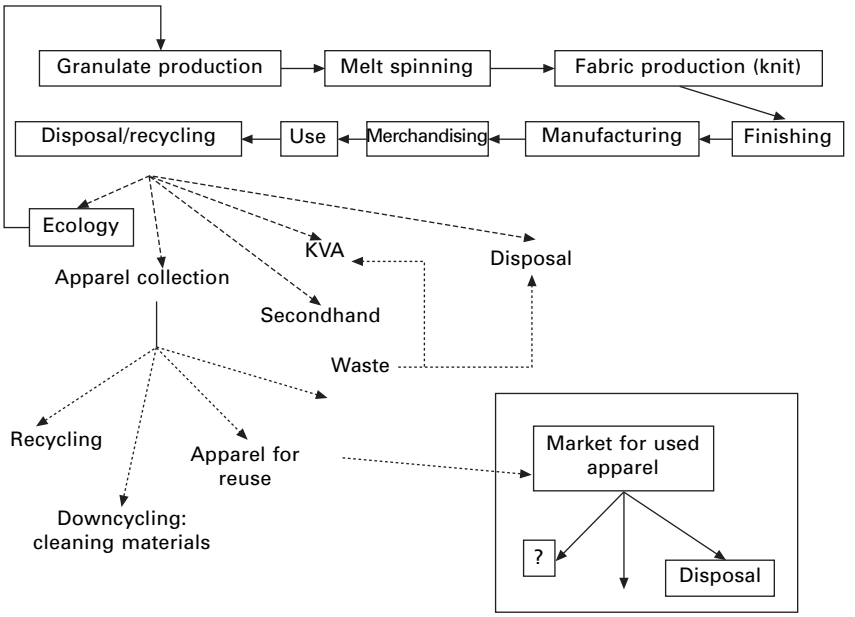
Thermal recycling

Thermal recycling of man-made fibers is economically best suited due to the high energy content.

Reuse

The above-presented recycling options are all based on destruction of material. However, there are options for reuse of apparel, if they have not yet

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2.65 Life cycles of a PES T-shirt with available recycling options. The company Ecolog developed a concept for collection and material reuse in injection molding or melt spinning, depending on the amount of collected material (source: Mathieu 2003).

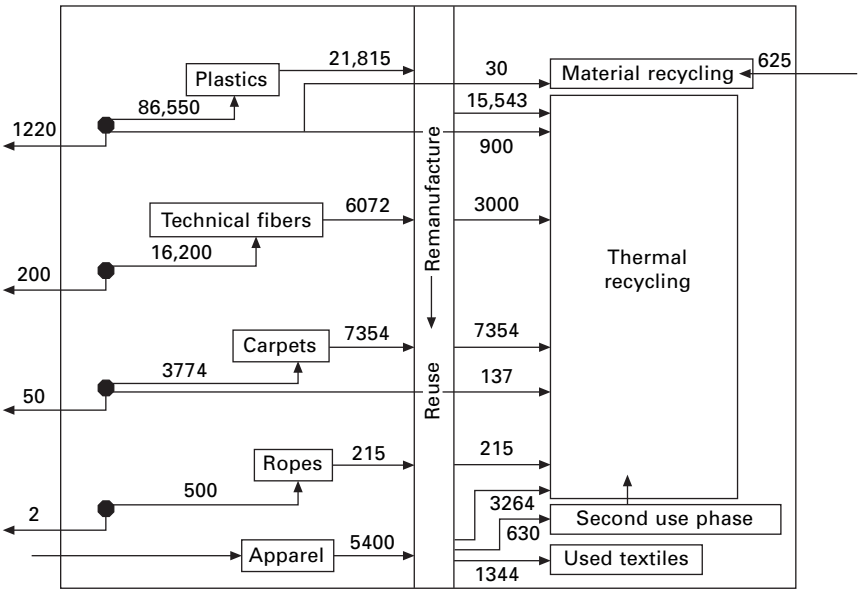
reached the end of their technical life cycle. Often the economic life cycle is shorter, because people do not wear clothes until they are damaged and so have reached the end of their technical lifetime. Every nation in Europe has built up an individual concept and system for collection of municipal waste, supplemented by collection systems for specific materials as well as collections on a private basis.

Polyamide material flows (Swiss case study)

The Swiss market for polyamides can be divided into five product groups: plastics (as granulate), technical textiles (fibers, yarns and woven fabrics), carpets (tufted carpets and floor coverings), ropes (for climbing and static) and apparel (see Fig. 2.66). Apparel represent a very complex group with only a minor share of polyamides. The following polyamide types are distinguished: PA 6, PA 6.6, PA 12, and a remaining group including co-polyamide and polyphthalamide as well as PA 6.10 and PA 6.12.

Considering the range of exports and imports of products in the Swiss market, the study found plastic parts to be the greatest fraction, followed by technical fibers, carpets and a very small fraction of ropes. PA 6 has by far

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2.66 Product-related material flows (tons) of polyamides for recycling and reuse (Swiss case study).

the largest application share with 44%, followed by PA 12 with 18% share and PA 6.6 with 11%. The rest consist of co-polyamides, polyphthalamides, PA 6.10 and PA 6.12 (Jaun 2005).

The sector for plastic parts is strongly export-oriented towards the automotive, electronic and machinery industry. Production of PA 6 and PA 6.6 is the largest part, whereas PA 10 is produced in small quantities. But there are also imports of polyamide granulate for plastics, partly in pre-manufactured form. The Swiss production of technical fibers splits into 55% PA 6 and 45% PA 6.6 and is mainly export-oriented with a share of 90%. The import of polyamide fibers is reported as a total of all fibers, of which a 50% share is assumed for technical fibers. Domestic production of polyamide fibers for the carpet industry is small compared to imports, though import statistics probably include all floor coverings too. Production of ropes represents the smallest fraction, but it is exclusively based on PA 6. For this reason it becomes interesting as a fraction purely for remanufacture. The production is export oriented.

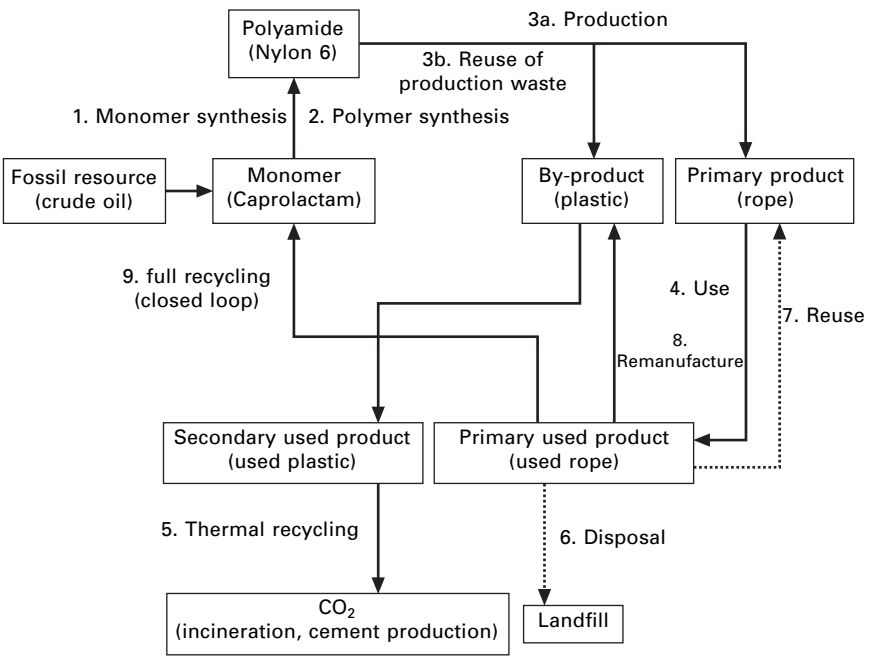
In order to reduce resource depletion and other environmental impacts in the life cycle of textile material, full recycling, reuse, remanufacture or downcycling and thermal recycling strategies become an interesting issue. Several studies on the recycling of packaging material such as PE, PP, PVC, PS and PET have been carried out (BUWAL 1991). However, recycling plastic parts from used products like electronic equipment seems to be

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impossible due to material mixes combined with additives applied in single materials (Oetiker 2001). This can be different for the recycling of fibers of pure material. A recent study has shown to what extent apparel made of pure polyester fibers and parts could be recycled or downcycled to material remanufactured by means of injection molding (Tobler and Mathieu 2003). The tests showed that only a combined processing with a large fraction of PET flakes is technically feasible. Other pure materials such as CDs proved to be recyclable without additional fractions. Processing with injection molding can be carried out also in relatively small quantities, but the critical point is the logistics for collection of the material after the use phase.

Polyamide, mainly as PA 6 and PA 6.6, is the basis for many applications and product groups. Accordingly, different strategies for full recycling, remanufacture, reuse and thermal recycling have been developed (see Fig. 2.67). Particularly, used carpets provide sufficient amounts of pure material for recycling either to virgin PA 6 and PA 6.6 or to plastic compounds. But some companies work with a lack of capacity (such as Evergreen in the USA) while others run below capacity (Tobler 2005).

Quite a considerable volume of waste accumulates during production processes in Switzerland, of which 1472 tons are exported and 1037 tons are processed as thermal recycling (in municipal waste incineration plants).



2.67 Recycling options for Nylon (PA 6.6) include full recycling, remanufacture, reuse, thermal recycling and disposal.

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Material recycling companies specialize in particular polyamide types and recycling types, whereby a small quantity of domestic waste and a large quantity of imported production waste are processed. The market is driven by prices for granulate and recycled granulate. However, quality requirements for PA 12 may inhibit the application of recycled granulate in some products.

If polyamide is brought to the waste incineration plant, there will be additional costs for treatment, and Swiss legislation bans disposal of combustible material. These facts favor recycling strategies. By evaluating the flows for recycling we can see that material recycling is performed for high-value polyamide (PA 12), driven by costs. A considerable fraction of production waste is either processed in thermal recycling or exported for full recycling. The question arises what the environmental impacts of these scenarios are. A specific focus is put on the remanufacturing option of the pure PA 6 fraction of ropes for plastic parts (see Chapter 4).

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3
Product specification function and textile process technology

Abstract: This chapter indicates ways to specify quality and functions of textile products and compares these with 'best available technology' (BAT) developed by the European Union. Textile specifications applied in electronic data exchange represent a competition factor, by increasing process control and pushing product development. Functionality as a guideline through the countless variations in apparel is defined and followed up along the value-added chain, showing how desired properties of a product can be achieved in specific processing and through interactions among properties.

Key words: textile specifications, textile functions, textile design, best available technologies (BAT).

This chapter is dedicated:

- to managers of the supply chain and to merchandising companies who want to apply textile specifications and environmental aspects of process technology in their sourcing
- to product development for communication of quality, function and sustainable production from fiber to apparel
- to scientists who wish to define scale and scope in life cycle assessment based on textile quality, functionality and environmental process technology
- to authorities who evaluate best available technology (BAT) of companies
- to the concerned consumer who wants to know about product quality and function.

3.1 Introduction

This chapter addresses the quality, the functionality of textile fabrics and the (best available) process technology of textiles and apparel. In the first section textile specifications are presented as an instrument for communication along the value-added chain (B to B) and towards the customer (B to C). The second section will introduce the aspects of functionality of a textile fabric, set by the generic fiber properties, yarn and fabric construction and finally finishing processes. Interactions between quality parameters from

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fiber to apparel will be outlined. Corresponding process technology for a desired quality will be indicated. The third section focuses on best available technology (BAT) for optimized environmental protection, as encouraged by the European Union (EU[1]), mainly for finishing. It is completed for the whole value-added chain by the author.

3.2 Quality and textile specifications

Arguing about the quality of a product opens discussion on precise definitions, known as specifications or quality parameters, and to whom these specifications will be revealed. In a holistic approach also environmental information has to be included, indicating the quality of environmental aspects. Also working conditions of employees and working safety could be considered. Such parameters are highly dependent on the technology applied as well as on the cultural context (Rivoli 2006).[2] They will not be included in the presented specifications, but should be part of a management system as shown in Chapter 1.

Textile specifications for all steps in the life cycle of textiles will be listed in this section. These specifications have been evaluated by several experts from ETH Zürich and Fachhochschule Albstadt, with data from COST Action 628 members (Walenius 2004a, 2004b and others), and are approved for general application. Dumitrescu (2002) and Ghituleasa (2002) showed nationally based differences from our findings. Highly specialized companies may need additional parameters. Textile specifications should be communicated in business relationships towards the client(s) but also towards the end consumer of the product. At company level there are process parameters like machinery setting, recipes and formulas as part of the internal quality inspection. Such parameters are not communicated, because they represent the knowhow of the company and thereby an important competition factor. They will not be the subject of this chapter. In the tables, the indication in the first column of the specifications is given as follows:

B for business communication along the value-added chain (suppliers/clients)
C for consumer information (product declaration) EPD
None for internal quality and environmental inspection (ISO 9000/14000).

3.3 Specification of raw material and processes

Among the various fiber materials, the main natural fibers such as cotton, bast fibers, wool and silk are specified. A selection of man-made fibers is presented as crude oil and as cellulose pulp based.

[1] http://ec.europa.eu/environment/ippc/
[2] From visits in the textile industry in Europe, USA, North Africa and Thailand.

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3.3.1 Cotton

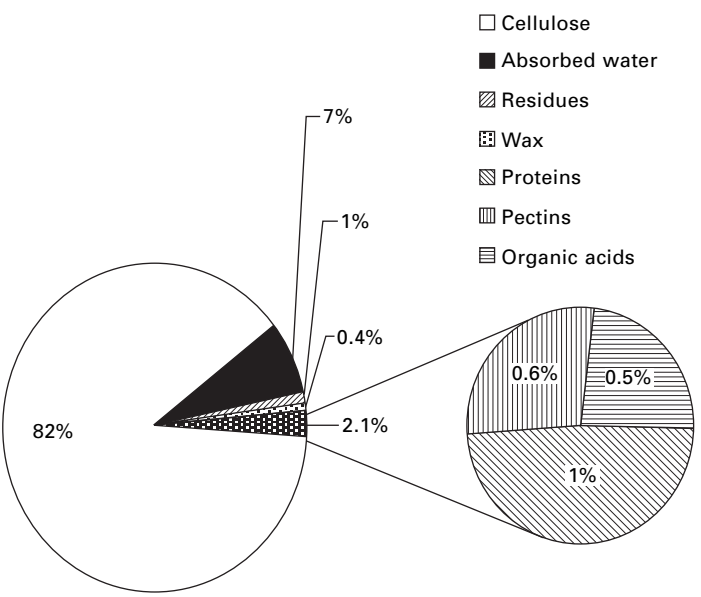
Cotton plays the most important role among natural fibers with a market share of more than 80% of all natural fibers.

Cotton growing

Cotton, grown around the globe in a tropical to sub-tropical belt between 30°N and 30°S, represents the largest agricultural area for textile fibers. Many of its superior properties in fiber processing are based on the composition of the fibers.

The content of a cotton fiber is complex, though most of the substance is cellulose (see Fig. 3.1). Particularly the absorbed water and the surface waxes make the fiber spinable. Further contents such as protein, pectin and organic acids contribute to the unique fiber properties and allow specific treatment in finishing. The quality of the cotton fiber is best in the field, the day a cotton boll opens (see also Chapter 2). Weathering, harvesting, ginning and manufacturing impair the natural quality of the cotton (Antony and Mayfield 1994).

Genetics, as studied by Meredith and Bowman (1998) and van Esbroeck and Bowman (1998), cottonseed quality (Emmett 2000), climate and soil conditions determine the staple length of cotton, as defined in Table 3.1. The longer the fiber the better is it spinnable. Key indicators for fiber growing



3.1 Chemical content of a cotton fiber.

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Table 3.1 Classification of cotton staple length

	Cotton staple length	
	mm	inches
Extra-long staple	>34.9	>1 5/16
Long staple	28.6–33.3	1 1/8 – 1 5/16
Middle staple	26.2–27.8	1 1/32 – 1 3/32
Short staple	<25	<13/16

are general agricultural parameters that are correlated to the limiting climatic conditions, which do not allow growing in areas with long winter seasons and limited temperatures in summer. There are differences in maturing time between individual varieties. In areas with short growing seasons the risk of low yield and inferior quality is high. Additionally the plant requires sufficient water supply in blooming time, whether by rainfall or by irrigation. Plant stress occurs in monocultural growing systems through pests and diseases (Bradow *et al*. 2000), as given in Chapter 2.

Table 3.2 gives the specifications for cotton growing. Some of the specifications are correlated to the seed input, others are correlated to the harvested cotton bolls. This fact points out the effect of the cotton yield.

Ginning

The fiber lint is separated from the seed by ginning. Three fractions are gained: cotton lint, cotton seed and trash. Depending on the harvest type, the fractions have a different magnitude. Table 3.3 gives examples of the fractions gained of handpicked cotton (in Greece and China) and stripper cotton (in Texas, USA), but the differences may even be larger than shown in these cases. The processes have to be optimized to get a sufficiently cleaned cotton with low fiber damage.[3] Typical specifications of ginning are given in Table 3.4.

Fiber quality measurement

The most common quality measurement system in global cotton trading is the High Volume Instrument (HVI), developed by Uster, now in its fourth edition. The quality parameters are listed in Tables 3.4 and 3.5. Further quality measurement methods are Shirley, Almeter and AFIS (Advanced Fiber Information System). Today also infrared measures (NIR) are used for maturity measurements (Hequet 2006). Classical GC–MS (gas chromatography – mass spectrometry) methods can be applied to analyze contents.

[3]An instrument to monitor ginning processes is IntelliGin by Zellweger Uster.

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Table 3.2 Specifications of cotton growing

Functional unit	ha/kg cotton and yield (kg)/ha	
Reference flux	kg lint/kg cotton	
Parameters (see Section 3.2)		
B/C	Variety	Species
B/C	Irrigation type	l/m^2
	Rainfall	mm
C	Land use	m^2/kg cotton
	Soil properties	Soil texture, moisture content
	Tillage	Low till, no till, full till
C	Energy consumption of cotton growing	kWh/kg cotton
	Seed treatment	g chemicals/g seed
B/C	Genetically modified	Type
C	Fertilizer	g/m^2
C	Organic matter	g/m^2
C	Crop rotation	Frequency/species
C	Beneficial insects	Inventory of species/m^2
B/C	Pesticides	g/m^2
B/C	Herbicides	g/m^2
B/C	Harvest aids, growth regulation	g/m^2
C	Energy consumption of cotton harvesting	kWh/g
C	Human work hours	h
B/C	Harvest type	Handpicked, stripper, picker, field cleaner
B/C	Yield	g cotton/m^2
	Yield allocation	lint/seed cotton
B	Moisture content	%

Table 3.3 Fractions in ginning from different areas

	Greece	China	USA	Unit
Lint (fibers)	154	207	251	kg/ton cotton bolls
Cotton seed	629	486	418	kg/ton cotton bolls
Trash	217	307	331	kg/ton cotton bolls

The automated HVI measurement analyses three samples of fiber bundles, which have to be fed by an operator. In the first sample, trash, yellowness and reflectance are measured by a video camera. Micronaire reading is carried out in a tube by means of air permeability with a second sample of about 10 g. In the third sample, length, uniformity, strength and elongation (of a fiber bundle) are measured. The fiber bundle is prepared by aligning the

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Table 3.4 Specifications of cotton ginning

Functional unit Reference flux		kg lint/bale Yarn number (tex)	
		Parameters	
B	Gin type	Roller, saw	
B	Lint cleaners	Number	
	Temperature	°C	
	Waste	kg/kg cotton	
B	Bale	kg	
	Energy consumption	kWh/kg lint	
B/C	Time of heating	°C and seconds	Data records
B/C	Fineness (micronaire)	Number	HVI data
B	Fiber length	mm	HVI data
B	Thickness of bundle	g/tex	HVI data
B	Fiber strength	CN/tex	HVI data
B	Short fiber content	% weight or number	AFIS data
B	Color grade (rd), yellowness	Number	HVI data
B	Trash content	g/kg	HVI data
B	Neps	Neps/g	AFIS data
B	Maturity	%	AFIS data
B	Wax	%	NIR
B	Stickiness	%	NIR
B/C	Pesticide in fibers	Chemical analysis	GC MS

Table 3.5 Quality parameters gained by the HVI measurements

Quality parameter HVI	Unit	Definition
Trash	% area	Measure of non-lint material in the cotton; correlates with the classifier's leaf grade
Reflectance	Rd	Indicates how bright or dull a sample is
Yellowness	+b	Indicates the degree of color pigmentation
Color grade		Three-digit code. Point of intersection of yellowness and reflectance in the Nickerson–Hunter color chart for Upland cotton
Micronaire		Measure of air permeability through a given mass of compressed cotton. Indication of fiber fineness and maturity
Upper half mean length	Inches	Average length of the longer half of the fibers
Length uniformity index	%	Ratio between mean length and upper half mean length of the fibers
Strength	g/tex	Force required to break a bundle of fibers
Elongation	%	Indication of elasticity of the fiber. Ratio of increase in length before breakage and original length

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fibers with a comb, and fixing with clamps. One measurement takes about 2 minutes. The parameters for measurements are given in Table 3.6.

The fiber preparation for AFIS measurements requires careful processing for precise results (Simonton *et al*. 2000). The cotton has to be prepared into slivers by hand before measuring. Three replications should be carried out for each sample. The slivers are sucked, one at a time, into the AFIS system and enter a mechanical process similar to opening and carding. This means that the fibers are measured after having been mechanically stressed. The system separates trash and dust particles from the cotton and individualizes the fibers. The individualized fibers are transported in a high-velocity air stream to the fiber sensor. They enter the sensor through a nozzle which presents them in proper orientation to a near infra-red ribbon beam. As the fibers pass through the ribbon beam, they scatter light in relation to their size and

Table 3.6 AFIS (Advanced Fiber Information System)

Quality parameter	Unit	Definition
Nep size	μm	Mean nep size per sample. Neps are entanglements of fibers
Nep count	Count/g	Neps per gram
Seed coat nep size	μm	Mean seed coat nep size. Seed coat neps are entanglements of fibers around a seed coat fragment
Total particle count	Count/g	Particles per gram
Mean particle size	μm	Mean particle size
Dust count	Count/g	Particles < 500 μm per gram
Trash count	Count/g	Particles > 500 μm per gram
Visible foreign matter	%	Conversion of the total particle count into percent
Length (w)	Inches	Length reached by 50% of the fibers
CV length (w)	%	Coefficient of variation of fiber length
Upper quartile length (w)	Inches	Length exceeded by 25% of the fibers
Short fiber content (w)	%	Percent of fibers < 0.50 inches
Length (n)	Inches	Length reached by 50% of the fibers
CV length (n)	%	Coefficient of variation of fiber length
Short fiber content (n)	%	Percent of fibers < 0.50 inches
Length 5% (n)	Inches	Length exceeded by 5% of the fibers
Length 2.5% (n)	Inches	Length exceeded by 2.5% of the fibers
Fineness	mtex	Mean fineness of the fibers in the sample
Immature fiber content	%	Percent of fibers with maturity <0.25, determines the maturity of the fibers between 0 and 1
Maturity ratio		Ration of fibers with maturity > 0.25 and total amount of fibers

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cross-sectional shape. This light is detected and translated into characteristic waveforms which can be interpreted by the AFIS. In the second sensor trash measurements are carried out in the same way. One procedure lasts about 20 minutes. (Information source: International Textile Center 1998.)

Case study: fiber quality, harvesting and ginning technology (Source: Liechtenhan, 2000)

Fiber quality has been evaluated in a case study in Lubbock, Texas. The scope for this study was set on the processes before baling, on raw material production. The effects in these processes on cotton quality are very important for later stages in production. Especially in yarn production, the cotton quality is of critical importance.

Traditionally, the color of the cotton is a main factor in pricing. The whiter the cotton, the better the price. Therefore, intensive cleaning seems to be essential. But the more cleaning is performed, the more damage is done to the fiber. Fibers can break by mechanical treatment, especially if they are dry. This reduces length and creates short fibers. They can also get entangled with each other and form little knots, called neps, which may cause thick and thin places in the yarn. It is difficult for the ginner to find the right compromise between trash removal and a minimal reduction in fiber quality (Antony and Mayfield 1994).

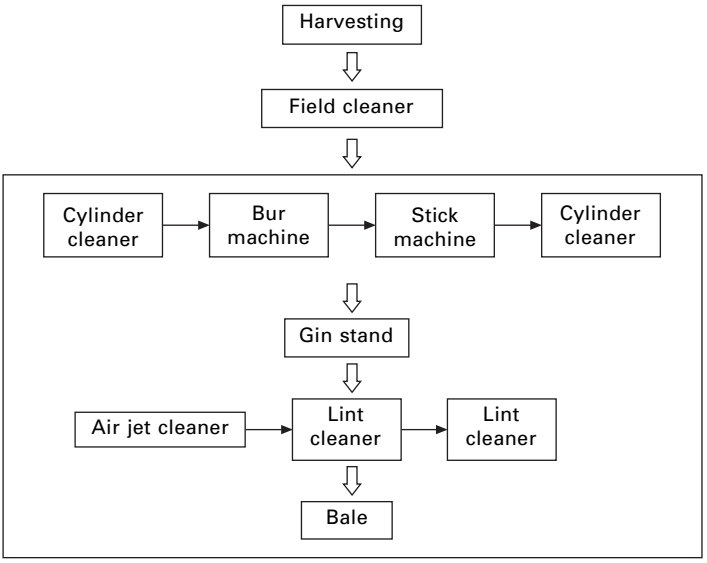
Klein and Schneider (1992) complain that there is no increase in quality value in the first process steps of the cotton industry – as the spinner would need it – but a reduction in value for practical application. According to the spinning industry, the quality of the raw material has decreased in recent years, although continuously better grades have been measured by Klein and Schneider (1992) and Demuth (1993).

Unfortunately this reduction in value for the spinner does not have an impact on the market price of the cotton. The specific quality parameters affected in cleaning are not represented in the current classification system. The High Volume Instrument (HVI) is constructed to measure short fibers, neps or immature fibers. A very precise instrument is able to measure these fiber properties is the AFIS (Advanced Fiber Information System), but it does not work as fast as the HVI and therefore cannot be used for standard cotton classification.

Effects of a field cleaner

Often the first step of cleaning is done already in the field in harvesting. The field cleaner is installed on the harvester. It breaks up bolls and sorts out burs, leaves and sticks. All this trash is left behind on the field (see Fig. 3.2). The setup of the quality measurement (Ethridge 1998) for this study is given in Table 3.7.

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3.2 Processes in harvesting and ginning. The harvested bolls are thermally treated in cylinder cleaners and mechanically treated in a bur and stick machine for removal of plant residues. In the gin stand the fibers are separated from the seed and cleaned in up to three lint cleaners until they are pressed into bales. If a field cleaner is applied in harvesting, a first cleaning step is carried out in the field. Consequently a stick machine can be replaced.

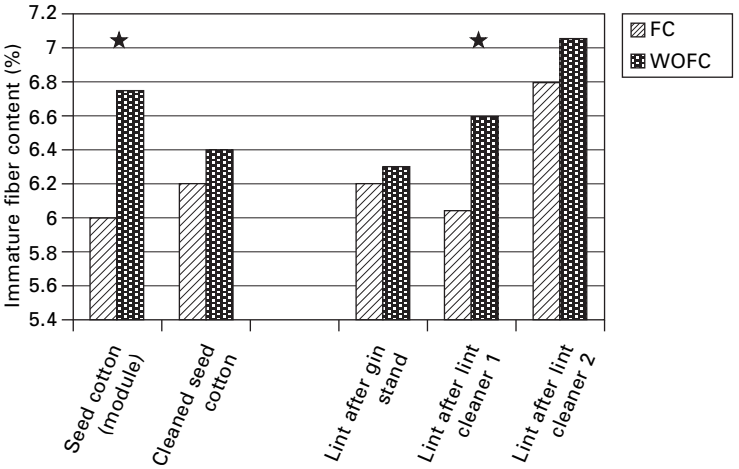
Table 3.7 Setup of sampling for cotton fiber quality evaluation with and without a field cleaner

	Sampling location in gin	Terminology in results
1	Module	Seed cotton (module)
2	Before gin stand (from overflow of conveyor–distributor)	Cleaned seed cotton
3	Before first lint cleaner	Lint after gin stand
4	Before second lint cleaner	Lint after one lint cleaner
5	Bale	Lint after two lint cleaners

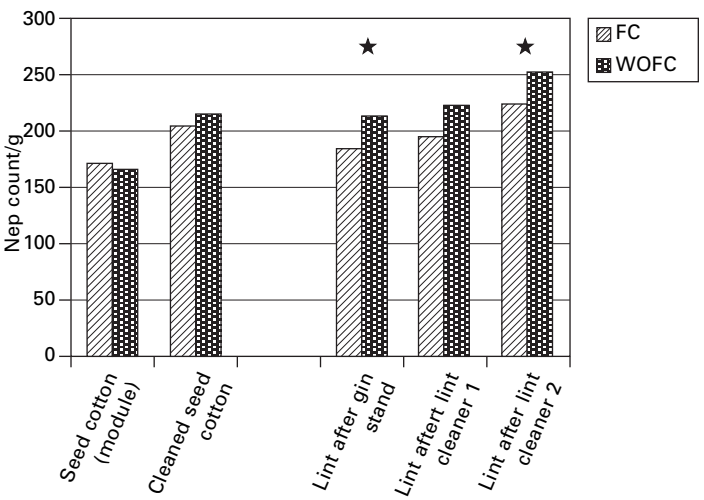
If an initial cleaning process is carried out in harvesting, allowing residues to be left on the field, fiber quality is influenced. The field cleaner reduced immature fibers in the cotton by about 7% (Fig. 3.3) and the amount of neps by about 10% (Fig. 3.4) even though the field cleaner performs an additional mechanical process and therefore a higher amount of neps would be expected. Micronaire values were significantly influenced due to the reduced immature fiber content. The effect was not price relevant, though.

No significant difference in trash or dust content can be observed between

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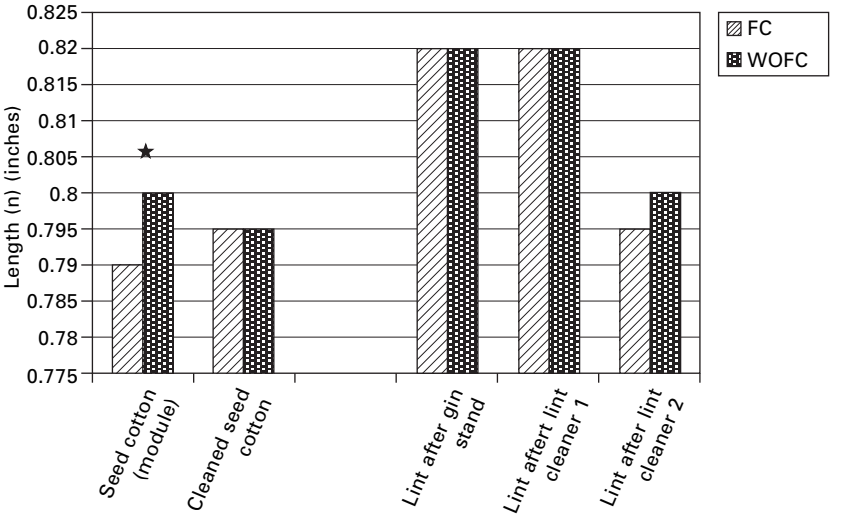
3.3 Immature fiber content of cotton processed with field cleaner (FC) and without field cleaner (WOFC). Stars indicate statistically significant differences. The field cleaner does a good job in reducing immature fibers.



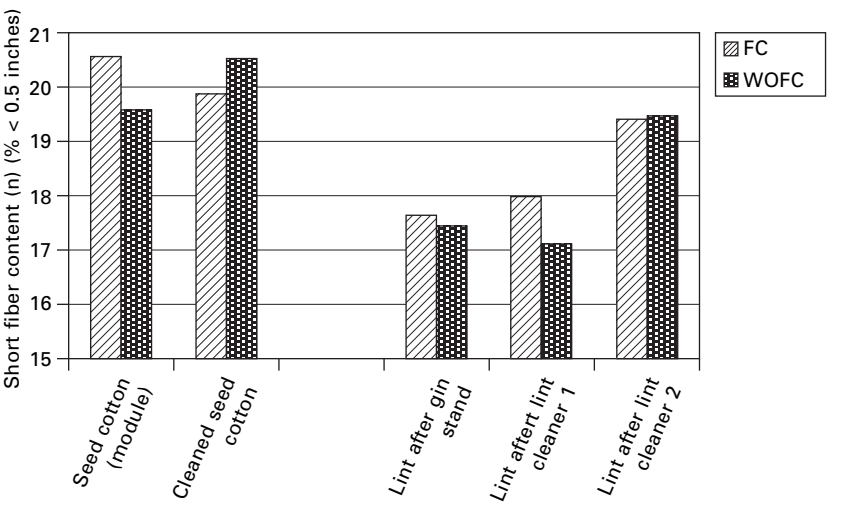
3.4 Nep count of cotton processed with field cleaner (FC) and without field cleaner (WOFC). Stars indicate statistically significant differences. For field-cleaned cotton the number of neps is significantly lower after the gin stand and the second lint cleaner.

the field-cleaned and not-field-cleaned cotton at the end of the process in the bale. The cleaning system of the gin levels the original difference. Figure 3.5 shows a highly significant difference in length (about 1/100 inch) between harvested field-cleaned and not-field-cleaned cotton. Correspondingly, the

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3.5 Fiber length (n) of cotton processed with field cleaner (FC) and without field cleaner (WOFC). The reduction in fiber length (of seed cotton) is statistically proven (star). In the following processes no difference was found, except for the last process. This indicates that field-cleaned cotton may require only one lint cleaning process.



3.6 Short fiber content (n) of cotton processed with field cleaner (FC) and without field cleaner (WOFC). No significant differences were found.

short fiber content seems to be higher ($p = 0.056$) (Fig. 3.6). The effect does not exist in further process steps, but there seems to be a trend with the second lint cleaner.

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Neither an influence on the trash content in the bale nor a significant influence on color or length could be found.

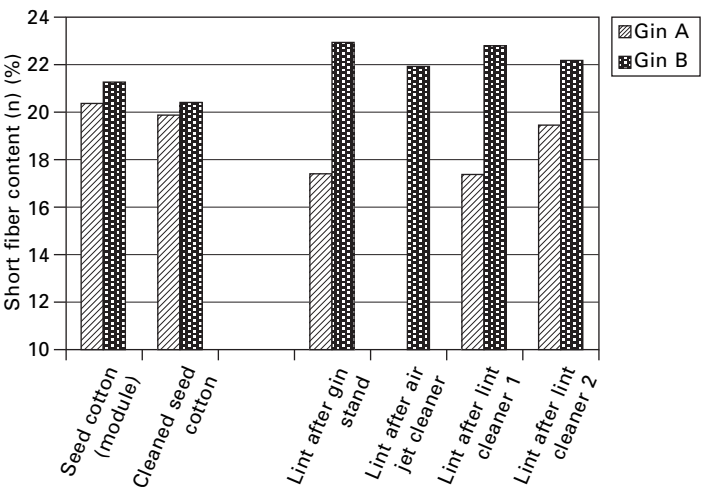
Effect of ginning process

Trash and dust content become smaller with every process step in ginning. Regarding length of the fibers, two effects are remarkable:

1. While the first lint cleaner of Gin A does not show a damaging effect, the second lint cleaner reduces length and increases short fiber content clearly (Figs 3.7 and 3.8). In comparison, the lint cleaning at Gin B seems not to have any negative effect.
2. The diagrams show that at Gin A the length of cleaned seed cotton is shorter than the length of lint after gin stand, which indicates that the actual ginning performance at Gin A is gentler to the fiber than the ginning with the modern fast-running Gin B. For Gin B the opposite is the case. The corresponding effect can be seen for the short fiber content (Fig. 3.7).

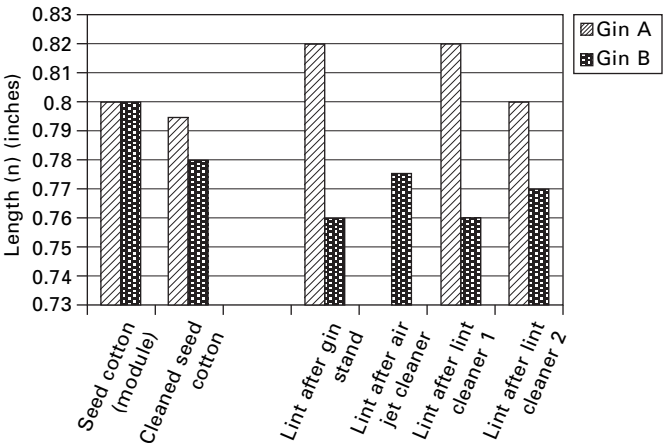
Adjustments in the cleaning configuration of the gin are required for field-cleaned seed cotton for increased strength (see Fig. 3.9). Less seed cotton cleaning will be necessary in order to reduce the mechanical stress on the fiber. Perhaps bur and stick machines can be bypassed.

Furthermore, attention has to be paid to the gin stand. The results of this study indicate that speed might be a critical factor for fiber damage. In

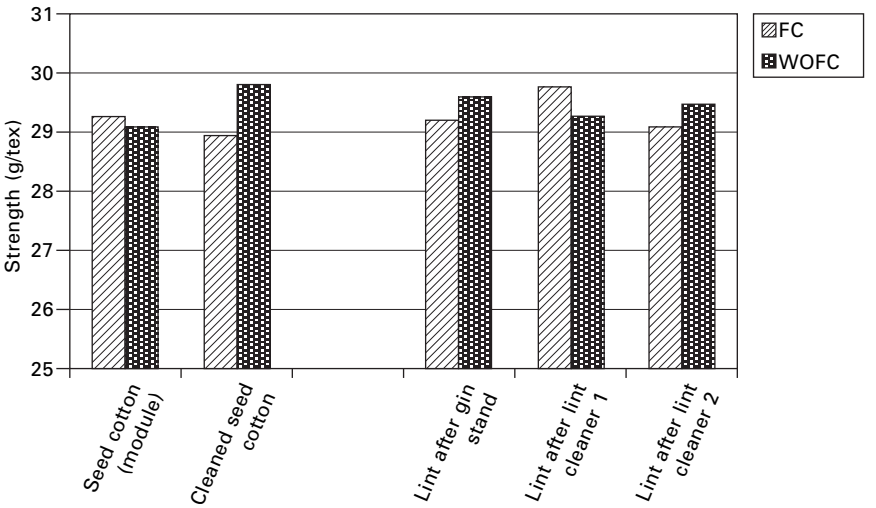


3.7 Short fiber content (n) of cotton processed in two different gins. Gin B, working with high productivity, produces a somewhat higher short fiber content than Gin A, operating with a lower productivity.

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3.8 Fiber length (n) of cotton processed in two different gins. Gin B, working with high productivity, produces somewhat shorter fibers than Gin A, operating with a lower productivity.



3.9 Strength of cotton fibers processed with field cleaner (FC) and without field cleaner (WOFC). No statistically significant differences were found, but a tendency is visible after the first lint cleaner, indicating that a second lint cleaning process for field-cleaned cotton could be omitted.

addition, improvements in cotton quality can be reached through less lint cleaning and by the implementation of process control systems in the gins (Liechtenhan 2000).

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3.3.2 Bast fibers (linen, flax, jute, hemp)

Only niche production exists in linen, flax and hemp fibers. Bast fibers were grown in Europe, North America and Asia in larger quantities until the nineteenth century. The specifications of growing bast fibers are representative for agriculture of rough, climate-resistant plants with few, if any, pests (Leupin 1999). Fiber preparation includes variations in retting (on the field) and decortication (separation of the bast) as well as fiber extraction with alternatives. Plant growth and fiber preparation are listed in Table 3.8. For fiber preparation process technology see also the section on best available technologies (BAT).

Cultivation of hemp in central Europe is marginal. Heller (2005) shows that for Eastern European countries, where larger areas are cultivated, there

Table 3.8 Specifications for bast fiber growing

Functional unit		ha/kg bast fibers and yield (kg)/ha
Reference flux		kg lint/kg bast fibers
	Parameters	
B/C	Variety	Species
	Rainfall	mm
C	Land use	m^2/g
	Soil properties	Soil texture, moisture content
C	Energy consumption in growing	kWh/kg bast fibers
	Seed treatment	g chemicals/g seed
	Fertilizer	g/m^2
	Organic matter	g/m^2
C	Crop rotation	Frequency/species
C	Beneficial insects	Inventory of species/m^2
C	Energy consumption in harvesting	kWh/g
C	Human work hours	h
B/C	Plant length at harvest	cm
B/C	Yield	g bast fibers/m^2
	Yield allocation	Fibers/wooden part
B	Moisture content	%
C	Retting type	Bacterial, fungi (field retting), chemical retting
	Decortication	Energy consumption in manual work
C	Fiber extraction type (degumming)	Steam explosion Ultrasound separation Chemical degumming Biological degumming
B	Impacts through fiber extraction	Dissolved organic content (DOC) Water consumption Energy consumption
B	Fiber fineness	tex
B	Fiber strength	g/tex
B	Fiber length	mm

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are considerable variations in growing practices, particularly in energy consumption.

The processed hemp fibers show a high tenacity, high absorption properties up to 95% against IR and UV radiation, and highest water uptake (Laib 1999); they are not conductive and provide a natural low flammability. The fibers had a 30% higher abrasion resistance than cotton fibers. Their good dyestuff uptake properties allow easy dyeing, but also their natural colors show many varieties. Besides these favorable properties that provide a high degree of wear comfort, some disadvantages have to be stated as well. The heavier fabrics are characterized by a dry and harsh touch, a tendency to wrinkle, a certain unevenness in yarn and fabric, and a possibly low dimensional stability and breaking elongation (3–4%). Jute production is still considerable in India with three main species, but specifications will not be outlined here.

3.3.3 Wool and silk

Wool and other animal hair

As shown in Chapter 2, domestic animals have changed in many ways compared to wild animals, particularly through selection and specific nursery conditions (Legel 1993). Selection was mainly aimed at increasing quantities and certain properties of meat, milk or other hair. Kraft (2000) found that only a few breeders in Australia were concerned about fiber quality.

Often, correlations between a healthy life for the animals and the quality of meat, milk and hair were neglected. Inbreeding of many generations in livestock husbandry often decreases the animal's fertility dramatically and increases genetic mutations of races. Uptake of toxic substances with nutrition and the composition of the nutrition find their consequences in deposits in the animal's hair (Schäfer 2004). Consequently, breeding conditions close to those in the wild indicate good fiber quality. Market preferences favor fine wool and leave European domestic wool production in a niche. Popescu (2004) described development processes aimed at higher quality. Table 3.9 gives the textile specifications for animal hair (wool).

Silk

Almost all silk moths are grown in cultivation and are treated in semi-industrial processes with one exception (see Chapter 2). There are no wild species left (Bulgheroni 2002) and man-made growing conditions are essential for the quality of the textile raw material (Prabha and Hardingham 1995). The cocoons are harvested, and damaged cocoons are sorted out to be processed to bourrette silk (as 'staple fiber'). Bourrette silk also includes silk filament waste of a certain length from reeling and twinning (see Section 3.3.6 below).

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Table 3.9 Specifications for wool and other animal hair

Parameters for animal hair		
B/C	Species	
B/C	Breeding	Domestic/wildlife
C	Density of the herd	Animals/ha
B/C	Illness	Number of antibiotic applications
	Preferred herb species	g/m^2
C	Pesticide contamination	g/m^2
B/C	Natural herd composition	Males/females/juveniles
	Herd rotation	Frequency/year
C	Herd protection	Number of injuries
C	Natural reproduction	Age/number of births
C	Health	Number of structural mutations
B/C	Shearing	Stress-less treatment
C	Branding	Removable dyestuff
	Scouring	Dissolved organic compounds (DOC/kg), water consumption (kg)
	Carbonizing	Lanolin extraction (g)
	Oiling	g/kg
	Carding	Energy consumption

Other by-products are fertilizer (because of the high nitrate content of the animal protein) and cosmetic powder (Haettenschweiler 2004) (see Fig. 3.10). Parameters for textile specifications are given in Table 3.10.

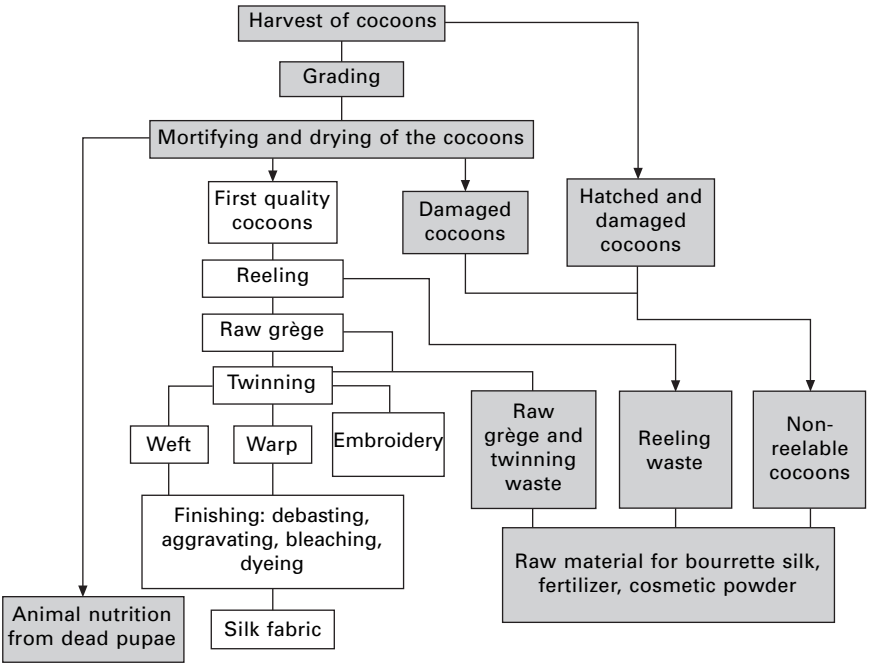
3.3.4 Man-made fibers from crude oil (polyester)

As shown in Chapter 2, production of fiber material for textiles is based on extraction of fractions from crude oil, followed by polymerization or poly-addition processes. There are several industrial process technologies available, often protected with patents (Weissermehl and Arpe 1994, Pfister 2002) that will not be the subject of this book. Textile specifications of man-made fiber quality and processing are shown in Tables 3.11 and 3.12.

3.3.5 Man-made fibers from cellulose pulp (viscose)

The basis for the natural resource of viscose is wood, grown in forests under the regime of forestry, which historically followed economic rules. Species with high qualities and large quantities for industrial purposes (furniture, pulp and charcoal production etc.) were harvested, often without renewing or followed by monoculture plantations. In the last decades forestry has developed guidelines for more varied functions of forests, including safety aspects, ecological criteria and value to society. These attempts have been made at both national and international levels, driven by forces to preserve

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3.10 Processing of silk. After drying of the cocoons different qualities are gained by selecting damaged cocoons. Also in reeling and twinning silk waste is produced and processed as bourette silk and by-products.

Table 3.10 Specifications for silk production

Parameters for silk		
B/C	Species	
B/C	Breeding	Domestic (wildlife)
C	Population density	Animals/m^3
C	Illness	Number of antibiotic applications
C	Pesticide contamination	g/g leaves
C	Breeding conditions	Number of early deaths/number of cocoons
C	Health	Number of structural mutations
B/C	Cocoon opening Sericin removal	Stress-less treatment Energy consumption
C	Reeling	Evenness of filament Energy consumption
B/C	Add load (sericin replacement)	Type of material g/m^3
B	Twinning	Energy consumption
B/C	Fineness	Number of filaments

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Table 3.11 Quality parameters of man-made fibers

Functional unit	dtex	
	Quality parameters	
B/C	Origin	
B	Staple length	mm
B	Structure of fiber, texturized, microfiber	Data records
B/C	Fineness	dtex/denier
B	Number of filaments	
B	Strength	cN/dtex
B	Spin dyeing	Data records
B	Monomers in final product	g/kg
B/C	Antimony in final product (only PET)	g/kg

Table 3.12 Specifications for PET granulate production

Process parameters			
Production of granulate			
	Process	Unit	Details
B/C	Total energy consumption	kWh/kg granulate	
B/C	Crude oil consumption	l/kg granulate	
	Production of *para*-xylol	Process energy/g chemicals	Oxidation in liquid phase
Synthesis of dimethyl terephthalate (DMT) (two steps)			
B/C	Catalysts	g/kg DMT	Reaction with
	Process energy	kWh/kg DMT	methanol DMT,
B	Reactivity (corrosion)		Combined etherification
B/C	Cooling energy		under pressure,
B	Purity	g/kg DMT	Crystallization,
B/C	Recycling of components	%	Two steps of cleaning (recycling)
Synthesis of terephthalic acid (TPA) (one step)			
B/C	Process energy	kWh/kg TPA	Esterification of second
	Catalysts		carboxyl group
B/C	Cooling energy (crystallization)	kWh/kg TPA	simultaneously with solvent, metal
B	Purity product	g/kg TPA	salt catalyst or as
B/C	Recycling of components	%	co-oxidation
Extrusion, melt spinning			
B/C	Energy	kWh/kg PET	
B	Granulate	kg/kg PET	
	Cooling water	m^3/kg PET	
	Water	m^3/kg PET	
B/C	Waste water	m^3/kg PET	
	PET-loss (waste)	g/kg PET	
B	Spinning preparation		
	Spin finish	type, g/kg PET	

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the world's natural functions (see Chapter 2). Process technology developed ecological alternatives on a laboratory scale (Struszczyk 2002) and an industrial scale (Schmidtbauer 2001).

The quality of viscose depends on processing (see Chapter 2). The first processes in the production of viscose fibers are in forestry up to the production of pulp, from which a large fraction goes into paper production (see Tables 3.13 and 3.14). The specifications for viscose and pulp production (with data by Urbanowski 2004) with carbon disulfide (CS_2) and N-methylmorpholine N-oxide (NMMO) alternatively are given in Tables 3.15 and 3.16.

3.3.6 Yarn specification

The most common yarn type is staple fiber yarn, spun from different staple fibers like cotton and other plant fibers, wool and other hair fibers, but also staple fibers from filaments.

Table 3.13 Quality parameters for viscose staple fibers

Functional unit		dtex, staple fiber weight (kg)
Quality parameters		
	Parameter	Unit
B/C	Fiber length	mm
B/C	Origin	Data records, label
B/C	Fineness	dtex
B	Strength (wet, dry)	cN/dtex
B	Heat resistance	Data records
B	Chemical resistance	Data records

Table 3.14 Specifications for pulp production

Process parameters for cellulose production		
	Parameter	Unit
B/C	Yield (harvest)	kg pulp/kg wood
B/C	Energy for timbering, sawing	kWh/kg wood
B/C	Separation of lignin	l alcohol/kg cellulose (recycling?)
B/C	Pulp dissolving	g sulfate/sulfite
B/C	Bleaching of pulp	g chloride/peroxide H_2O_2
	Pulp pressing	Energy consumption
	Packaging	Purity (contamination with sea water)
	Transportation	Energy consumption
B/C	Dilution of cellulose	l NaOH/kg cellulose,
		Water content, pH
		NaOH recycling
	Process time	Length of chains (C)
	Maturing with oxygen	Viscosity

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Table 3.15 Specification of viscose production (conventional method) with finishing processes

Production of viscose staple fibers (conventional method)		
	Parameter	Unit
C	Total energy	kWh/kg viscose
	Water consumption	l/kg viscose
	Preparation of sulfidation	l N_2/kg viscose
	Production of xanthogenate	l CS_2/kg viscose (recycling)
	Stabilizing viscose	l caustic soda (NaOH)/kg viscose
	Deaeration	mg air/kg viscose
B	Filtration	purity (%), ENKA viscose
B	Spinning	l H_2SO_4/kg viscose (recycled) l NaOH/kg viscose Number of spinning nozzles Pressure, *p*
	Elongation	Changing of perforated bobbins
B	Washing	l water/kg viscose Sulfur content/kg viscose
B/C	Bleaching	Sodium hypochlorite, H_2O_2/kg viscose
B	Brightening	Type, kg/kg viscose
B	Matting	g titanium dioxide/kg viscose
	Drying	Energy/kg viscose
B	Additives, zinc sulfite, zinc sulfate, wetting agent	l/kg viscose
C	Waste water	l/kg viscose
C	Airborne emissions	g AOX/m^3 air

Table 3.16 Specification of viscose production (NMMO method)

Production of viscose staple fiber (NMMO process*)		
	Parameter	Unit
C	Energy	kWh/kg viscose
C	Water	l/kg viscose
B	Cellulose	l/kg viscose
	NMMO	l/kg viscose
B	Brightening agent	kg/kg viscose

* N-Methylmorpholine-N-Oxide

Filament yarns are produced in continuous mechanical–chemical processing, whereby the specifications are set in accordance with the man-made fiber type.

Silk filaments are processed in manual reeling of several filaments, whereby uniformity in diameter of the reeled silk is aimed at. The naturally decreasing diameter of the individual filament has to be equalized through

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manual arrangement. Specific twinning is applied depending on the further function as warp, weft or knit yarn.

A successful spinning mill records many parameters which are not communicated towards business partners or end consumers, but contribute to improving quality and enabling economic production (Meyer 1999a, 2000). As examples, bale layout and drawing parameters (Ramkumar 2000) are mentioned. Testing of yarn quality (Cybulska 1998, Faerber and Soell 1997) and continuous improvement according to ISO 9000 are indispensable operations for the cotton fiber market. General requirements for sustainable mass production are based on quality parameters according to Meyer (2002). Downstream processing proves to have a high influence on yarn quality (Bischofsberger 1994). Typical cotton type yarn specifications for yarn quality and processing are given in Table 3.17.

3.3.7 Weaving specification

One way to produce a two-dimensional fabric is weaving, whereby quality parameters as well as process parameters are specified (see Table 3.18). Main activities are in sizing optimation (Steidel 1999, Dittrich-Krämer 1999) and recycling (Stegmaier *et al.* 1999).

Quality inspection remains a time-consuming visual process, which so far has not been replaced by automated systems, although concepts are available (Meier *et al.* 1998). The results are not as good as with manual inspection. Additionally, the manual control system includes repair of defined failures.

The weaving process in practice requires many more settings, which will not be communicated towards business partners but are part of the internal quality management. Sprengruber and Steinhart (2000) elaborated fabric specifications and appropriate machinery settings, as shown in Tables 3.19a and b.

3.3.8 Circular knitting specification

Several quality parameters set fabric standards and process standards, by which the fabric quality is produced. Andraschko (1997) investigated correlations of machinery settings and process technology with product quality of knitwear (see Table 3.20). Such adjustments, performed by the knitter, are not communicated.

3.3.9 Finishing specification

Some of the quality parameters like dimensional stability, pilling, abrasion and breaking strength could be measured already in the gray fabric, but most of

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Table 3.17 Specifications of staple fiber spinning

Functional unit		tex, g/km	
Quality parameters			
B/C	Type of yarn	Spinning technology Yarn construction Type of fibers, blended yarn	Type Data records Data records
B/C	Fineness	Tex	Mettler balance, Zweigle yarn reel
B	Tenacity	cN/tex	Uster Tensorapid
B	Elongation at break		Uster Tensorapid
B	Twist	T/m	Zweigle twist tester
B	Evenness CV m	%	Uster Tester
B	Thin places	Counts per km	Uster Tester
B	Thick places	Counts per km	Uster Tester
B	Neps 140%	Number per km	Uster Tester
B	Hairiness Conditioning	% % humidity	Uster Tester
B	Bobbins	Type and material Mass Length of yarn Winding density Hardness	Data records kg km Data records Data records
B	Paraffin wax	g/kg yarn	Data records
Process parameters			
B	Spinning technology Bale setup Machine setup Production planning	See Q-parameter Country of origin Fiber parameter Spinning plans Plans of production	 Schedule Schedule
B/C	Quality inspection	Auto leveler Adjustment of yarn cleaner Yarn breaks (end downs)	tex Data records Number/10,000 m
C	Waste	Incinerate (g/kg) Fiber recycled (g/kg) Noils (g/kg)	
	Production energy Energy used in air conditioning	kWh/10,000 m Suction, change of air	Data records kWh/10,000/tex x/h
B/C	Total energy	kWh	

them are changed by finishing processes. The example of dimensional stability shows that many parameters in dimensions and flexibility of the fabric may contribute for the definition of one property. In Table 3.21 the contributing quality specifications are listed together with units for measurements and

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Table 3.18 Specifications in weaving

Functional unit		Mass (kg) and running meter
Quality parameters		
B/C	Width of fabric	cm
B/C	Weight	g/m^2
B/C	Warp density	Warp counts/cm
B/C	Weft density	Counts/cm
B/C	Binding pattern	
B/C	Repeating of pattern	cm
B	Stops (warp and weft yarn breaks)	Thread breaks per 100,000 m
Process parameters		
Weaving preparation		
B	Warp length	m
	Fabric width	m
	Warp assembling	Warping, warping
	Engery consumption	kWh/m
	Knotting, threading	Mechaniccal/manual hours
	Article exchange	Min per batch or lot
Sizing		
B	Energy consumption	kWh/m
B/C	Amount of size	g/m
	Type of size	CMC carboxymethyl cellulose, PVA, starch, acrylate
B/C	Recycling	%
Weaving technology		
B/C	Weaving technology	Machine type
B/C	Fabric type	Terry weaving double chains, etc.
	Design	Weave
	Machine settings	Wrap tension
		Weft insertion/min
	Weaving	

test standards for quality measurement. Another critical property is pilling, defining the appearance of apparel after a certain number of wear and care cycles. Pilling is a complex phenomenon and depends on many factors of fiber quality and yarn construction, as shown in Section 3.2.

Pilling and abrasion can be tested in the Monsanto quality test. The result, measured in cycles, stands for lifetime of a fabric (see Fig. 3.11). Such results have not been communicated to the consumer so far, because the relation between the cycles in test conditions is not easy to relate to a certain use phase. The stress on a fabric may be different for different movements a person carries out during a day. Practical tests on different movements and

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Table 3.19 (a) Product specifications in weaving; (b) machinery setting for a specified product on a given machine type

(a)	
Warp	100% PES, filament yarn
Weft	100% CO
Warp fineness	dtex 106, f 136
Warp density	30 counts/cm
Warp density selvage	15 counts/cm
Weft variations	9,20 tex, 20,10 tex, OE 24,72 tex, OE 38,85 tex
Weave pattern fabric	Canvas, denim
Fabric width	176 cm
pattern width	173 cm
selvage width	1.5 cm
Fabric weight, gray	g/m^2
Fabric weight, finished	g/m^2
Gear change	1:60
Air pressure	Left = 2.8 bar, right = 4.8 bar
Number of shafts of fabric	6 (number 1–6)
Number of shafts of selvage	2 (number 7, 8)
Shaft sequences (from back)	7 – 8 – 1 – 2 – 3 – 4 – 5 – 6
Strands per shaft (fabric)	900
Heddles frame (selvage)	10
Strands per shaft (fabric) (from left)	L3 = 155 , L2 = 500 , L1 = 245
Strands per shaft (selvage)	L1 = 20
Drop wires (fabric)	5400
Drop wires (selvage)	44
Tracks for drop wires	3
Type of creeling	Direct
Number of yarns per drop wire (fabric)	1 y/drop wire
Number of yarns per drop wire (selvage)	1 y/drop wire
Number of yarns per strand (fabric)	1 y/strand
Number of yarns per strand (selvage)	1 y/strand
Number of yarns per shaft (fabric)	2 y/tube
Number of yarns per shaft (selvage)	1 y/tube
Speed	Picks/min
Production	76.1 kg

(b)

C	Electrical energy	kWh/m
C	Speed	picks/min
C	Compressed air	kWh/m
B/C	Water consumption	m^3/m
C	Noise, vibration	db
B	Aerosols, dust	PM
	Failures	%
	Waste	m/1000 m
	Second choice	m/1000 m
	Air filtration	kWh, change of air (x/h)

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Table 3.20 Specifications in knitting

Functional unit		Weight (g) and meter
Quality parameters		
B/C	Loop courses	Number of loops/10 cm^2 Number of rows/10 cm^2
B	Loop length	mm
B	Fabric type	Flat or circular knit
B	Fabric dimensions	Width or diameter (cm)
B/C	Pattern	Type
B	Defects	Defects/m
Process parameters		
B	Machine type	Diameter, working width, systems machine fineness
	Speed	U/min
	Peripheral devices	Types
	Knotting	min/batch
	Productivity (change of article)	min
B/C	Design	Single jersey, interlock, ajour Repeat length RL, RR, LL
	Machine settings	Steering program
B	Oil for needles	Type, g/kg knit
	Air conditioning	kWh water (m^3)
	Waste air	m^3/m
	Aerosols, dust particles	PM 10
	Noise, vibrations	db
B	Quality inspection	Defects/100 m

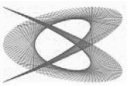
Table 3.21 Quality parameters and standards which are correlated to the dimensional stability of a fabric. Generally knitwear shows lower bulging resistance than woven fabrics, while woven fabrics often show lower wrinkle resistance than knitted fabric

Dimensional stability	Unit	SN/DIN/EN-Norm
Number of loops	Loops and rows/cm	SN 198431
Yarn count	Warp and weft/cm	
Fabric weight	g/cm^2	SN 198433
Bulging resistance	mm	SN/EN 25077
Shrinkage	mm	
Elasticity	%	SN 198670/EN 22313
Wrinkle resistance (Monsanto)	Visual	
Wrinkle resistance after washing and drying	Angle (standard comparison)	

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Measurement

- Pretreatment: air conditioning: 23°C, 65% R.F., 24 hours
- The test fabric is moved in a Lissajous pattern by means of a standardized pilling element (wool fabric) on defined pressure
- After a defined number of cycles the surface of the fabric is evaluated
- At the appearance of the first damage (hole) the test is stopped and the number of cycles is stated



Lissajous

Test requirements

Equipment:	Martindale Model 102
Pilling element:	Original standard fabric SM 25
Pressure:	1.2 N/cm

3.11 Martindale test for abrasion: test definition and requirements.

activities correlated to pilling and abrasion tests would improve communication about quality and expected lifetime duration towards the consumer.

General quality parameters for finished fabrics are listed in Table 3.22, without covering all aspects. Process parameters set standards by which the quality parameters have been achieved (see Table 3.23), indicating also the environmental quality. Most of them are used for internal process control as in scouring (Hartzell and Hsieh 1998, Buschle-Diller *et al*. 1998), textile auxiliaries (Beck 1999) and dimensional stability. But some of them, like water and energy consumption are also of interest for the consumer (BAFU 2003). Waste water contamination is a wide-ranging area of environmental concern, well monitored by Bahorsky (1997). Solutions towards zero effluents were developed by De Vreese (2002, 2003).[4]

3.3.10 Specification in cut and sew

Cut and sew has to deal with two major areas. First, the transformation of a two-dimensional fabric into a three-dimensional apparel is a demanding process. It requires a knowledge of technology and material properties to find an appropriate cut for dimensional changes in various parts of the final product. The final decision is highly influenced also by the seasonal style and cost considerations for industrial manufacture. Secondly, industrial manufacture for unspecified consumers bears the uncertainty whether the apparel will fit the person or not. Fit of apparel is achieved by definitions of individual body mass. As the human body shows infinite variations in shape, it seems almost impossible to define a generally applicable base of parameters, based on body measurements. In manufacturing practice standardization in

[4] Personal communication in 1998.

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Table 3.22 Quality parameters in finishing

Functional unit		Weight (g) and meter	
Quality parameters			
B/C	Pilling	SN 198525	Cycles
B	Abrasion resistance	SN 198529	Cycles
B/C	Dimensional stability	DIN 53870, SN-EN 25077	% shrinkage
B	Bursting pressure	DIN 53861	cN/cm^2
B	Resistance to flexing	DIN 53362	
B	Color leveling	Visual	
B/C	Color fastness	ISO EN SN 105 N02	Scale (1–8)
B/C	Light fastness	ISO 105 – B02	Scale (1–8)
B/C	Wash fastness	ISO 105 – C06	Scale (1–6)
B/C	Rubbing fastness	ISO EN SN 105 D02, X12	Scale (1–8)
	pH	–	1–7
B/C	Fastness to perspiration	ISO 105 – E04	Scale
B/C	UV-absorption	Australian Standard	Photometric
B/C	Wrinkle resistance	EN 22313	Visual
B/C	Air permeability	ISO EN SN 9237	
B	Conditioning for testing	DIN 53802	
B/C	Fabric type	Fiber blend	%

size parameters is discussed but not yet implemented (see also the section on functionality).

Recently developed measurements for body indexes should be established with typical combinations of indexes grouped to a size, from which gradation is constructed. In individual tailoring, the customer's measurements are taken for the construction of the apparel. Some fabric parameters can assist the manufacturer to produce high quality apparel, equipped for stress by the movement of the person wearing it (Quaynor *et al*. 1999). The fabric should resist forces that tear it out and work on seams of the apparel (see Table 3.24).

Countless specific quality requirements for sewing depend on style and fabric (Hu and Chung 2000) of individual products. Only limited quality parameters are proposed (see Table 3.25) because process parameters take a central position.

3.3.11 Specification in merchandising and consumption

In an ideal merchandising process, apparel is developed to meet all expectations a consumer may have. Evidently this is in reality hardly ever the case. A set of technical specifications can assist product development at least in the technical area, if the same parameters are evaluated over time. They are a mix of functionality and textile specifications, communicated along the value-added chain, among other criteria (see Chapter 5). The better quality aspects can be communicated towards the consumer, the more the value of a product

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Table 3.23 Main specifications in finishing

Process parameter		Units	Remarks
Energy			
B/C	Electrical energy	kWh/m	
	Source of electrical energy		Hydropower, coal, nuclear power, etc.
	Thermal energy	kWh/m	
	Source of thermal energy		Gas, oil, etc.
	Energy recovery	kWh/m	Heat exchange
Water consumption			
	Pretreatment	m^3/kg fabric	
	Dyeing/printing	m^3/kg fabric	
	Finishing	m^3/kg fabric	
B/C	Water recycling	m^3/kg fabric	
Pretreatment			
	Detergents	g/kg fabric	Phosphonates, APEO, free tensides
	Emulators	g/kg fabric	Surfactants
	Complex former	g/kg fabric	Chelates, EDTA
	Anti-foaming	g/kg fabric	Silicon compounds
	Desizing agent	g/kg fabric	Possible sizes: starch, PVA, polyacrylate, CMC (carboxymethylene-cellulose)
	Reducing agent		
B/C	Bleaching	g/kg fabric	NaH_2S (sodium hydrosulfite), NaOH, NaOCl (sodium hypochlorite), sodium chlorite (for PET)
	Brightener	g/kg fabric	Phosphonates
	Heat-setting	Temperature, time	Only PET
	Alkaline	g/kg fabric	Only PET
B/C	Mercerization	g/kg fabric	NaOH, ammonia

Table 3.24 Fabric strength consists of several strength measurement types, whereby the forces along the fabric (tearout force and tear propagation load) as well as the perpendicularly oriented bursting pressure and flexural stiffness are tested. Due to its inherent elasticity, knitwear resists higher forces than woven fabrics, based on the same yarn parameters. Forces also affect seams and stitching positions of apparel, depending on finishing processes applied and sewing thread properties

Tearout force/elongation	N/cm	
Tear propagation load (Elmensdorf)	N/cm	SN 198482
Seam tear resistance	N/cm	
Stitch tear resistance	N/cm	EN 388
Bursting pressure	N/cm	DIN 53862
Flexural stiffness (cantilever)	N/m^2	DIN 53362

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Table 3.25 Specifications in manufacturing

Functional unit		Piece of apparel
Quality parameters		
Cut, body mass fit		
Size, gradation		
Process parameters		
B	Energy consumption	Electrical energy Thermal energy
	Human work	Ergonomics
C	Textile waste	kg/kg tailored fabric, application/disposal
B/C	Accessories	Kind, material, pollutant-free
B	Sewing thread	Material, % of shrinkage, color
B/C	Embroidery	Material, % of shrinkage, color, fastness
B/C	Labels	Material, % of shrinkage, color, fastness

becomes aware to the buyer. However, to find the appropriate criteria for communication is a difficult task, as this should satisfy the busy consumer as well as the concerned consumer. Basically all information about product development should be available: the summary of all specifications, labeled with C (see Table 3.25). These parameters include most customers' complaints and consequently the properties consumers want. Preferably there would be categories for consumers with reference to the lifetime duration, and how the latter is influenced by the individual parameter. Other parameters define care and wearing properties which are essential for consumer satisfaction with the product. As addressed in the third column of Table 3.26, harmonized categories for communication could be elaborated as an equivalent to the technical specifications. Merchandising should improve in communication of quality parameters between product development and the point of sale.

Table 3.27 summarizes a short version of quality parameters which should be available at the point of sale. Personnel should be trained to know such parameters not only in theory, but also in practice (see Table 3.27).

Many marketing decisions are included in merchandising processes. The relevant parameters define quality but also environmental performance of the activities. They are addressed in Table 3.28.

Although information is available in different places, the processes of laundry as carried out by consumers could be optimized. Information on water quality (hardness), laundry agents (including dosage) and energy consumption of the equipment have to be combined. The parameters are listed in Table 3.29.

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Table 3.26 Quality parameters for product development (* = pollutant tested according to Eco-Tex 100 standards)

Fiber material	Type	Information for consumer
Origin (yarn)	Country	Information for consumer
Yarn count	tex	Information for consumer
Fabric: strength	cN	Define categories
Knitwear: bulging behavior	%	Define categories
Pilling	Cycles	Define categories
Dimensional stability	%	Define categories
Seam resistance to shifting	mm	
Water uptake	g/cm^2	Define categories
Water delivery	g/cm^2 s	Define categories
Light fastness	Scale	Define categories
Wash fastness*	Scale	Define categories
Pilling resistance*	Scale	Define categories
Perspiration fastness*	Scale	Define categories
Special finishing	Type	Information for consumer
Water repellency	x	Information for consumer
Oil repellency	x	Information for consumer
Flame retardancy*	x	Information for consumer
Wrinkle resistance	x	Information for consumer
UV absorbency	x	Information for consumer
Antimicrobial property*	x	Information for Consumer
Pollutants tested according to Eco-Tex 100	Heavy metals Pesticides Tin organic compounds Chlorinated organic carriers Volatile organic compounds VOC pH value No carcinogenic dyestuffs Finishing: no antimicrobials (except for phenol), no flame retardant, formaldehyde or PVC	
Information for care	Laundry: temperature Ironing: temperature Dry cleaning: type Bleaching: yes/no	
Water consumption	l/kg recycled textile cloth	
Detergents	l/kg recycled textile cloth	
Other auxiliary agents	l/kg recycled textile cloth	
Energy supply	kWh/kg recycled textile cloth	
Distance of transportation	t km	

3.3.12 Specification for recycling and disposal (apparel and textiles)

Recycling and disposal of textile material (Table 3.30) follow national waste treatment legislation and available knowhow (Mathieu 2003, Jaun 2005).

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Table 3.27 Quality parameters at the point of sale

Functional unit	Cloth (type of)
Main quality parameters for selling	
Material	Raw material, fiber blends
Yarn construction	Type
Fabric construction	Type, weave, knit, counts
Color fastness and evenness	Scale
Dimensional stability	% (knit)
Pilling	Cycles and equivalent
Handle/fall	Kawabata method
Functionality	Water uptake, moisture transport, temperature regulation, UV absorbance, antimicrobial, etc.
Surface properties	Wrinkle resistance, pilling
Special properties	Records
Care properties	Bleaching, washing, ironing, drying, cleaning

Table 3.28 Specifications for merchandising

Process parameters	
Transport for distribution	km (round trip)
Packaging	Material, quantity or amount/kg cloth
Point of sale	Marketing, positioning, parking places Design of selling area, presentation, lighting
Labels	Information content
Personal assistance	Knowhow, time for consumer
Service	Fitting

Table 3.29 Specifications for consumption

Process and quality parameters for consumers	
Washing cycles	kg laundry per week
Filling per volume	kg laundry per volume (%)
Dry cleaning	% of total laundry per week
Laundry process	
Water consumption	l/kg laundry
Energy consumption	kWh/kg laundry
Detergent consumption	l or g/kg laundry
Softener	l/kg laundry
Optical brightnener	l/kg laundry
Special treatment	l or g/kg laundry
Tumble drying	
Energy consumption	kWh per kg laundry
Ironing	
Energy consumption	kWh per kg laundry

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Table 3.30 Specifications for recycling and disposal

Functional unit	Piece of apparel
Quality parameters	
Blend of material	% mixture
Additives	Chemical and physical characteristics
Hazardous waste fraction	%
Fraction for landfill	%
Fraction for combustion	%
Fraction for recycling	%
Process parameters	
Water consumption	l/kg recycled textile material
Detergents	l/kg recycled textile material
Other auxiliary agents	l/kg recycled textile material
Energy consumption	kWh/kg recycled textile material
Transport distance	km/kg recycled textile material

3.4 Functionality and process technology

Product development must add the necessary functionality for a specific use, ensuring the required quality of the product is achieved. This task requires knowledge of fiber properties as well as all production process variations, taking into account the many interdependencies between the two parameters. Optimized functionality is achieved by determining the apparel type and setting up consistent functions step by step along the production process. This procedure is addressed in Section 3.10 and Table 3.31. For an overview it is recommended to consult that section before starting with setup of functionality (Sections 3.4 to 3.10).

Historically, applied natural fibers were known over centuries for their functionality. The choice of the fiber was made according to the climate and season. As in earlier centuries, when spinning and weaving were done by hand, the variations through processing were limited and this choice was very important. In industrialized textile manufacture more and more variations became customized by means of new technology with diversified options for processes and functions. Only in the second part of the last century did new man-made fibers provide new functionality, and finishing processes were developed for attractive solutions to add in functions to both natural and man-made fibers. Specifically, water management of the human body has achieved a high importance for comfort and insulation (see Table 3.32). Many new surface properties are generated or improved in finishing.

In product development from fiber to apparel such relations are given step by step, as will be explained in an example. A quality-oriented cotton spinner knows exactly what yarn specifications are appropriate for a knitted sweatshirt or a fine woven blouse in order to fulfill the functionality in knitting

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Table 3.31 Setup and validation of functions for individual apparel categories

Setup of functions								
*****	*****	*****	**	**	*****	*****	*****	Fibers
**	*****	*****	*****	*****	**		**	Yarn
*****	*****	*****	*****	****	*****	*****	****	Fabric
*****	*****	*****	*****	**	*****	*****	*****	Finishing
**	*****		*****	*****	**	**	**	Cut and sew
Water management	Mechanical protection	Hand	Drape	Fit	Thermal insulation and regulation	Barrier function	Washing temperatures	
Water uptake and retention	Durability, abrasion, pilling	Touch	Stiffness, surface structure, wrinkle resistance	Elasticity, mobility	Air permeability, thermal conductivity	UV/EMC, flame, water, oil, etc.	Thermal stability	
*****	*****	*****		*****	*****	*****	*****	Baby wear
*****	**	*****	**	*****	*****		*****	Underwear
*****	**	*****		*****	*****	**	**	Nightwear
*****	*****	*****		*****	*****		****	Socks and stockings
*****	*****	*****	**	*****	*****			Pullovers, sweaters
**	*****	*****	*****	***	**	**	*****	Men's formal shirts, ladies' formal blouses
*****	*****	*****		*****	*****		****	Men's casual shirts, ladies' casual blouses

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**	*****	**	*****	**	**		*****	Men's formal suits, ladies' formal suits
**	*****	**	*****	**	**		*****	Ladies' formal dresses
**	*****	*****	**	*****	*****		****	Ladies' casual dresses
*****	*****	**	**	*****	*****	**	****	Ladies', men's and children's casual upperwear
*****	*****	**	**	*****	*****	*****	****	Ladies', men's and children's outdoor wear
*****	**	*****	*****	*****	*****	*****	*****	Sportswear
*****	*****			*****	*****	*****	*****	Work wear

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Table 3.32 Physiological effects of fibers on the human body are measured by different properties in water management (water uptake and transmission, evaporation, condensation and drying) and physical properties which are correlated with the water management

Water uptake	$g/cm^2/min$
Water transmission	$g/cm^2/min$
Evaporation	$g/cm^2/min$
Condensation	$g/cm^2/min$
Drying process	$g/cm^2/min$
Thermal conductivity	$W/cm^2{}^oC$
Electrostatic properties	Coulomb
Antistatic properties	Siemens

or weaving. This may include fineness, twist, strength and application of wax (see the section on specification). The designed yarns are soft or stiff, more or less hairy or elastic, if designed as core yarn. Often the spinner also produces blended yarns with polyester or viscose staple fibers for improved strength or lower costs. He may know about pilling effects of yarns with short fibers, but does not develop this function. He may also know that water uptake and moisture transport in fabric made of blended yarns is different from that in pure cotton yarns, but he does not develop this function actively. Product development of apparel also makes use of multifilament yarns, which are specified by chemical fiber producers, including the quality parameters fineness, number of filaments, strength, elasticity (Regenstein 2006), shape of the filaments (Schweizer 2006), biocompatibility of filaments (Bruenig *et al*. 2006), etc. The quality parameters of the filament yarn define the functionality of the fabric in water uptake (Itsuma and Kuroda 2006), moisture retention, pilling resistance, elasticity and so on in an area that could not be provided by a staple fiber yarn.

Such innovations in chemical fibers also call for adaptations in extrusion machinery (Nasri 2006). Moreover, certain properties and functions can be introduced in various steps in product development. Wrinkle resistance can be achieved in finishing by means of specific chemical treatment of the surface with resins but also by application of a specifically designed twinned yarn. Demands and requirement from the market considering new functions and properties become an increasingly important competition factor for companies. The trend also goes towards more wear comfort, as is provided by apparel with high water absorbency and moisture transport, elastic properties and a soft touch. But often marketing trends are not in line with functionality. Consequently functionality of a product has to be developed in close cooperation with the partners along the value-added chain of products.

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3.5 Inherent functionality of natural fibers

The functionality of natural fibers is given by the function a plant fiber or an animal hair is assigned to. They have high affinity to human skin (Renner 2000). Animal hair shows high insulation and protection properties for cold climates as evaluated over millions of years, while plant fibers may have the function of reproduction or stability of the plant (if situated in stems). As part of a biological organism, plant fibers preserve their natural function of water uptake given by the biological structure. However, their moisture transport is limited, because they are separated from the biological organism, where specific elements are developed for water transportation.

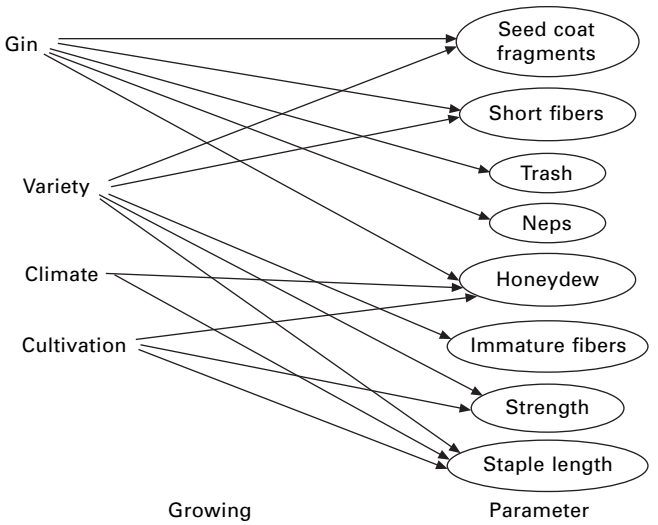
3.5.1 Cotton

Fibers are extracted from the cotton fruit capsule, the cotton boll, grown out of the plant's blossom. The biological function of the cotton lint is the distribution of seed by winds, whereby the fine and light fibers serve as transportation vehicle. The fineness and smoothness of the fiber make cotton a favorite for apparel with skin contact. Individual cotton growing, harvesting and ginning influences a number of fiber quality parameters. The main parameters are staple length, strength and micronaire, which are determined by variety, cultivation methods, climate and weather conditions (Emmett 2000). Infections with aphids may produce honeydew, a secretion which degrades cellulose to sugar.[5] Trash content and seed coat fragments are set mainly by weather conditions and harvesting technology, but they are also influenced by the ginning setup. Harsh ginning decreases trash content but may produce additional neps in the fibers and increase the short fiber content (see Fig. 3.12), as we found in our Texas cotton study (Liechtenhan 2000).

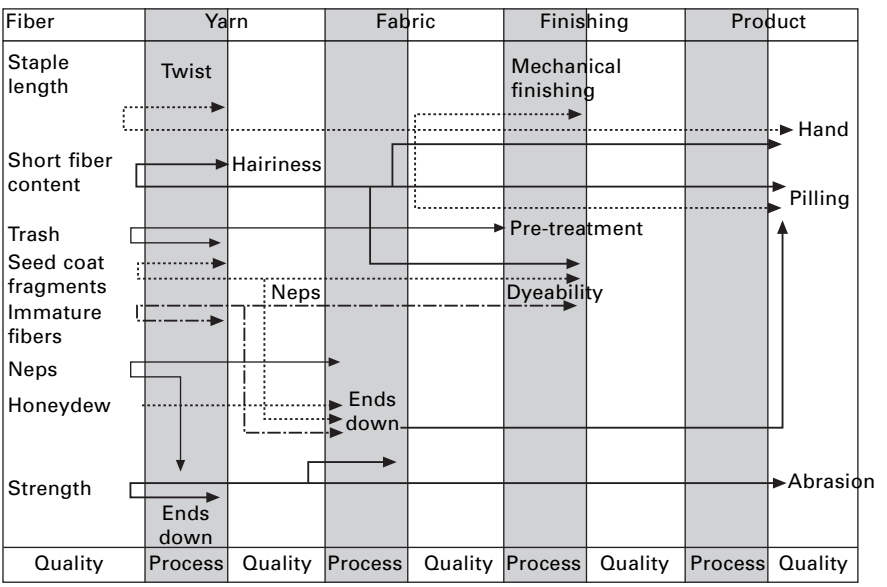
All these factors cause changes for the further processing in spinning, weaving and finishing and thereby also functionality of the individual process steps as shown in Fig. 3.13 (Bradow *et al*. 2000). Inferior fiber quality (seed coat fragments, low micronaire, neps, honeydew and strength) is likely to cause damage such as ends down, thin and thick places in spinning processes and ends down in weaving processes. Low micronaire (of immature fibers) also influences the dyeability in finishing. The effect of a high short fiber content and low fiber strength due to inferior fiber processing (Robert *et al*. 2000) is manifested in the use phase through faster abrasion and pillling of apparel. The skill of spinning, weaving and finishing experts is to recognize the weak points and to improve the quality of the end product by appropriate processing (see Section 3.7).

[5] From visits to in the Texas High Plains in 1999 and 2000 (see research program).

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3.12 Cotton growing, ginning and genetic factors (variety) determine fiber quality parameters for further processing.



3.13 Influences of fiber quality on yarn and fabric quality.

3.5.2 Flax, linen and hemp

The bast fibers are gained from the vegetative part of the plant: stems of flax, linen or hemp plants. Consequently the quality parameters for these fibers

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are developed before the harvest of the fruits. This is particularly important for hemp, whose fruits are used as drugs for the tetrahydrocannabin (THC) content of their flowers. Industrial hemp varieties generally show low THC contents, and stems are harvested before fruiting because the desired quality of the bast fibers is achieved before the fruits are mature. Consequently no coproduction of fruit oils is possible. Harvest of the stems has to be adapted to the fiber application, followed by the fiber extraction. The fibers, gained from stem material, are based on cellulose and hemicellulose material compounded with lignin. They have to be extracted from this compact system. The processed fibers are longer than cotton fibers and have to be degraded in diameter for cotton-like skin comfort.

3.5.3 Wool and other animal hair

Animal hair (from sheep, goats and other mammals) which developed as an insulating element has gone through a long period of adaptation to climatic conditions and can be considered as the natural product suited for mankind. But the different orientation of the hair in woven, non-woven and knitted applications leads to a degradation of functionality compared to the living animal: the insulation cannot be regulated by movement of the individual hair, allowing more or less air permeability. Additionally, seasonal changes are associated with the growth of more or less short hair to provide perfect insulation. The natural grease on the hair makes it completely water repellent and gives protection against rain for the animal. However, there are large differences in the hair qualities, particularly in length and fineness, due to the different climates where the species or races live.

Yarn and fabric constructions aim to express inherent properties of the fiber. The dense formation of woolen fabrics results in too warm apparel for warmer climates. Other animal hair from llama, vicuña, angora, mohair or cashmere goat is applied for the finest luxury apparel with a very low weight but with properties comparable to those of wool.

Wool is flame retardant by nature, a property which opens applications other than for apparel, like home textiles (upholstery, etc.). Due to its structured surface, wool also takes up particles and can transport them inside the fibers. Processing with high temperatures and friction, operations that animal hair is not exposed to in nature, causes felting of the fibers by degrading the protein structure.

3.5.4 Silk

Silk gained from the cocoon around the pupa of a moth is the only natural filament. Its natural function to protect the developing pupa is associated with balancing properties to provide appropriate moisture and temperature

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(below 40°C) for biological functions. In cultivation the development time follows the temperature, as given by nature. The silk filaments are attached by means of sericin, a natural glue, which is removed for further textile processing. This separation reduces the weight and volume of the filament, which also leads to a loss of mechanical protection. The individual filament, originally produced by the female silk moth silk glands, shows a shrinkage in diameter with progressive spinning, the filament becoming thinner. In the manual reeling process, where several filaments are brought in line, this has to be leveled out by adjusting the overall diameter with sectoral assembly of silk filaments. The fragile structure so gained determines application for delicate apparel production. Silk is considered to be 'skin friendly' by regulating temperature, especially in warm climates. Its high water uptake and moderate moisture transport properties make silk a material suited for fine apparel and underwear.

3.6 Designed functionality of man-made fibers

Man-made fibers produced from crude oil fractions or regenerated natural resources (see Chapter 2) show significant differences in functionality (see Table 3.32) compared to many natural fibers, based on their chemical and physical structure (see Table 3.33). Generally the water uptake of man-made fibers is designed for the function; it can be lower or higher (superabsorbents). Their moisture transportation is better than that of many natural fibers, but unless specifically finished their thermal balance properties are inferior. Table 3.34 gives an overview of filament properties of the main man-made fibers. Alternatives within the individual fiber types are based on changes in the composition of molecular chains (chemical properties) as well as in the drawing process (physical properties).

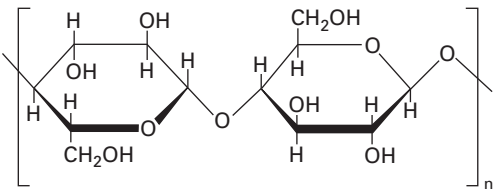
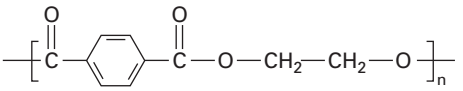
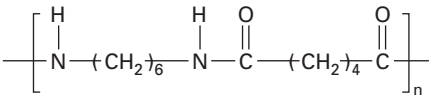
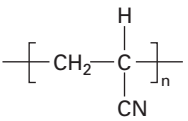
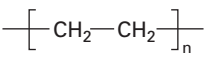
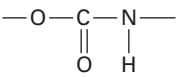
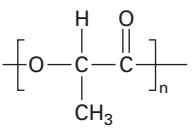
3.6.1 Fiber construction

Melt-spun filament yarns are manufactured (1) with options in the number of mono filaments, (2) with defined fineness, and (3) in the form of the filaments. The latter is set by the drilling of the spin nozzle. Fineness is achieved particularly in crystallization, which is determined by the raw material and the drawing process. Surface properties can be altered for desired (optical) functions. However, man-made fibers can be designed in many ways according to specific requirements already at the stage of filament formation. Modifications in formulas and refinement of machinery open countless variations which influence the functionality and processability of the textile material (Bruenig *et al.* 2006, Schweizer 2006).

Generally functions are designed by the spherical arrangements of the macromolecules and their chemical interaction (Richter 2006). Many

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Table 3.33 Chemical structure of man-made fibers

	Viscose
	Polyethylene terephthalate (PET)
	Polyamide 66 (PA 66)
	Polyacrylonitrile (PAN)
	Polyethylene (PE)
	Elastane
	Polylactide

For terminoloy see www.bisfa.org/booklets/index

filaments can replace staple yarns and add new functions, particularly in water management (see Table 3.34). The functions of flexibility and strength can be achieved better with fine filaments than with (natural) staple fibers. Surface properties can be introduced by means of different technologies.

3.6.2 Elasticity

By drawing, the macromolecules become oriented along the yarn's axis. Especially for polyester, additional heating is required to achieve crystallization. The drawing process is defined by the velocity the yarn is exposed to. It provides the setting of the physical properties (degree of crystallization), the so-called orientation of the yarn: low oriented yarn (LOY), partially oriented yarn (POY) or fully drawn yarn (FDY). The elastic properties of LOY and POY are not reversible.

In newer fiber development higher elasticity is added by introducing

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Table 3.34 Properties of man-made fibers. Thermal conductivity and electrical charge are indicated as low, medium (med) and high. The electrical charge depends on humidity and fiber preparation

	PET	PA	PAN	CO	CS	Wool	Silk	Linen
Moisture regain (%)	0.2–0.5	3.4–4.5	1.0–1.5	7–11	12	25–30	9–11	8–10
Water retention (%)				40–45	90–120	40–45	40–45	50–55
Breaking force (cN/tex)	25–65	40–60	20–35	25–50	18–35	10–20	25–50	
Heat influence limit (°C)				125	125	100	100	150
Melting point (°C)	250–265	215–260	Degrades					
Thermal conductivity				med	med			
Electrical charge	high	high	high	low	low	low	low	low
Glass transition temperature (°C)			80–95					

changes in the molecular geometry (Van den Driest 2004) in filaments like polypropylene. Master batches, added to the raw material, highly influence crystallization and thereby functional properties (Evaraert 2004). With such changes in functionality, advantages of natural fibers can be matched and new functions for technical applications can be created.

3.6.3 Structure, surface properties and functions

The variety of structures within microfibers (very fine filaments) is produced by means of different spin nozzles to create variations in the shape of their profile. The new structures create new optical variations through reflections within the structure, but also offer countless options for filling in liquids in the new volume so gained, to be emitted in time. Such structures are interesting for medical applications (Rothmaier 2006, Mathis 2006).

If a bulky yarn surface is desired, filament yarns have to be texturized. Several technologies have been developed. In a physical process the yarn is heated until it softens. Thereafter it is exposed to slight turbulences by airflow, allowing thermoplastic deformations which are permanently fixed by cooling. The appearance of the yarn becomes curly, whereby the tenacity of the filament is not changed.

Specific applications of lubricants and additives (Wild 2004 for polypropylene) can add or reduce properties like luster of the yarn, improved UV protection and other surface properties. Nanotechnologies like plasma treatment can be

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applied in order to change surface properties of the yarn dramatically (Stegmaier 2004, Fischer 2004), even if this technology is in its emerging stage. Surface properties of the yarn contribute to the touch of the fabric; they also influence absorption properties in finishing. Thereby functions like antistatic properties, flame retardancy, dyestuff and water uptake can be applied. Nanotechnologies open new horizons on the level of molecular changes in the surface of very thin layers. Applications may cover the Lotus effect (Stegmaier *et al.* 2006) up to dosage of medical applications or electronic properties of surfaces. The technology is still in its pioneer phase with only some hundreds of products being actually on the market in the EU. Experiences of environmental impacts caused by the nanoparticles are missing so far. But with an increasing number of products the uncontrolled emission of fine particles may cause undesired pulmonary effects. Dilution in fresh water by laundry processes may cause unknown impacts on fauna and flora. Isolation of harmful, finely distributed substances is technically not feasible.

3.7 Spinning processes: functionality in two dimensions

The desired yarn qualities are achieved as a combination of fiber properties and setup of the processes in either staple or filament spinning, whereby different technologies are available (see Chapter 2).

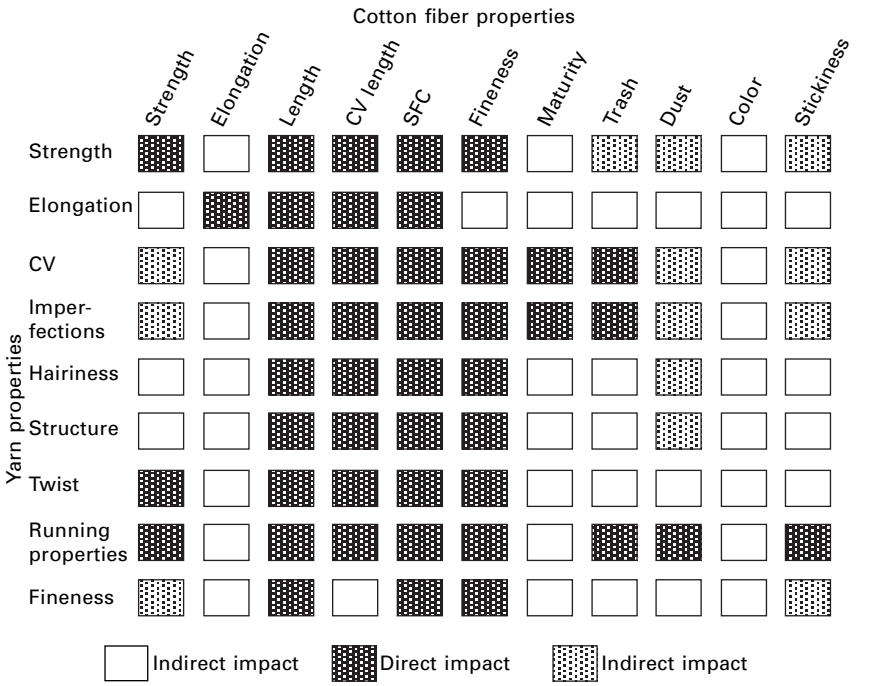
3.7.1 Functionality in staple yarns

The functionality of a staple yarn is determined by the fiber quality parameters, yarn construction and quality achieved by the chosen spinning technology by means of individual machinery settings. The fiber properties have to be selected accordingly for the desired yarn quality. Most prominent fiber properties for yarn formation in ring spinning technology are staple length and micronaire for embedding of fibers, whereby natural waxes increase the stability. Gantner (2004) developed a model for fiber movements, allowing predictions of the yarn function. Classical parameters of staple yarns like strength, elongation and hairiness are set by fiber parameters (see Fig. 3.14).

3.7.2 Functions

The properties of the yarn are set by the given technical specifications in combination with the fiber quality parameters (Lloyd and Taylor 1998, El Mogahzy *et al.* 1998). The main fabric categories are weft and warp yarns for woven fabrics and yarns for knitwear. The prior requirements are fineness and strength as well as low abrasion. While the fineness must be adapted to the desired fabric weight (knit or woven), strength is determined by the

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3.14 Correlation matrix of cotton fiber properties and yarn properties. CV = uniformity, SFC = short fiber content.

function of the apparel. Thereby the structure of the yarn is influenced by yarn construction and machinery settings. Strength can be increased by appropriate twist of the yarn and selected yarn constructions like ply yarns or core yarns. Fineness is adjusted by selecting the spinning technology (ring spinning for very fine yarns), the appropriate machinery settings and the yarn construction.

Yarns for knitwear are less twisted than weft yarn. Warp yarns need a higher twist for higher strength. Yarns for knitwear are generally equipped with a paraffin film for protection.

Very fine yarns are produced only in ring spinning technology. For reduced hairiness at equal yarn quality and low pilling, compact spinning technology is applied. Reduced hairiness is required mainly for fine and/or printed knitwear. The choice of spinning technology (ring spinning, compact spinning, OE spinning, and friction spinning) determines the strength and hand (harshness or softness) of the fabric and thereby its application for underwear or upperwear (jeans, trousers, skirts, jackets).

3.7.3 Spinning technology and machinery settings

Ring spinning machinery has been developed specifically for cotton fibers and

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is adapted to these fiber properties. Other natural fibers like wool or hemp can also be processed on this machinery. Both fibers have increased fiber length compared to cotton. Bale opening and carding are common processes for all spinning technologies, whereof ring spinning is the most universal technology for all fiber types (see Chapter 2). Blending with man-made staple fibers (cut filament fibers) can be achieved on the drawing frame by mixing different fiber slivers in the desired quantity. Very fine yarns (<10 tex) can only be produced with ring spinning technology. In ring spinning technology the carded and drawn sliver is reduced in its fineness in two succeeding processes: roving and ring spinning. High quality yarn is fed to a combing process before roving, where 10% to 18% of the short fibers are removed from a lap of slivers. Combers, the removed short fibers, can be fed to products with lower quality requirements.

Rotor spinning technology (OE = open end spinning) is the choice for shorter fibers, for fibers with a high amount of impurities and for coarser yarns, but also for lower production costs. In rotor spinning the sliver's fineness is reduced on an opening roller. It is sucked into the spinning rotor, where individual fibers are disposed in a circular fashion in the fast-rotating chamber, the spin box, and finally are attached to the yarn, fed from the same side of the rotor. Characteristics of the yarn (Ramkumar 2000) are built up by the drawing coefficient, the rotation speed and the form of the navel of the spin box. The yarn structure is built up by a different formation process (see Fig. 3.15).



3.15 OE spinning from cans with carded sliver. A travelling piecing robot repairs ends down.

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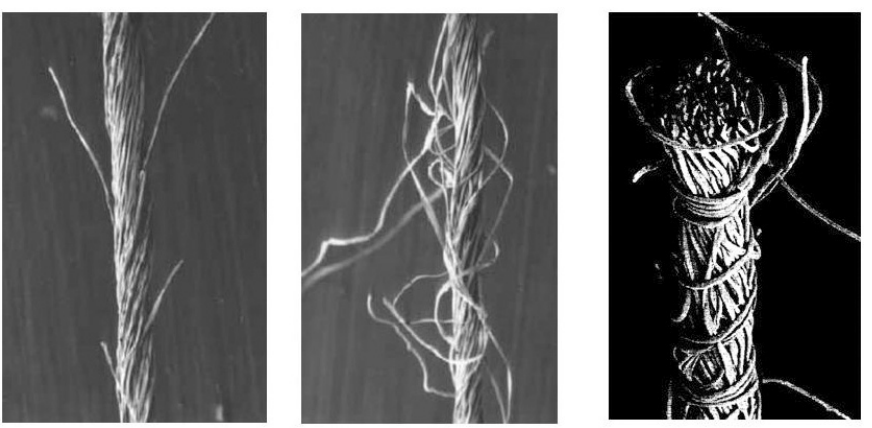
The arrangement of the spin boxes allows winding of the yarn on large cones, ready for transportation. The twist of the yarn is set by the rotation speed (rpm) for desired fabric functions. Rotor spun yarn and ring spun yarn show different structures under the microscope (Fig. 3.16).

Although compact spinning is a new development, it is based on the ring spinning process and can even be carried out on machinery adapted accordingly. The so-called spinning triangle, the part between the drawn roving and the insertion of the twist, is reduced. Non-embedded fibers are aspirated, which produces a less hairy yarn with fewer neps (Artzt *et al*. 2001). The result is a fine yarn with more evenness and less hairiness. The good integration of fibers with compact spinning as well as combing contribute to reducing pilling effects in apparel as indicated in the specification for consumption (see Table 3.23).

Machinery settings are adapted in carding, drawing and spinning in order to reduce short fibers and neps, parallelize fibers or introduce more or less twist, and also for ecological optimization (Schmidt 2002). The individual setup of the spinning equipment is determined by the function of the yarn. The fineness (tex) is set by drawing parameters in roving and ring spinning (see Fig. 3.17).

3.7.4 Yarn constructions

Additional properties can be introduced into yarns by a variety of yarn constructions. The simplest one is a ply yarn forming a stable, dense yarn. The original yarns are spun mainly in the Z direction, and the twisting is in the S



Compact spun yarn Ring spun yarn Rotor spun yarn

3.16 Rotor spun yarn and ring spun yarn show different structures under the microscope.

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Settings		Intermediate control		Setup of equipment	
Alpha (m)	100	Delivery (m/min)	25	Production (kg/h)	200
Twist (turns/m)	1000	Fineness flyer (tex)	360	Number of bobbins	15,041
Rotation (U/m)	25,000	Drawing per process	36.0	Efficiency (%)	97.9
Fineness (tex)	10	Waste (%)	1.5		
Efficiency (%)	90.0	Production per bobbin	0.013		
Production (kg/h)	0.014				

3.17 Example of settings for ring spinning of a long staple warp yarn (10 tex). Permanent intermediate control of yarn defines quality as well as productivity. The appropriate setup of spindles allows a high efficiency of the intended production of 200 kg per hour.

direction, forming a very stable fabric construction in weaving and knitting. Ply yarns have always been an alternative for yarn sizing to increase strength for weaving processes. On the other hand, they show reduced flexibility, a function which can be corrected by appropriate finishing.[6] Today ply yarns have become even more important because yarns with different properties may be combined, and thereby new functions are created.

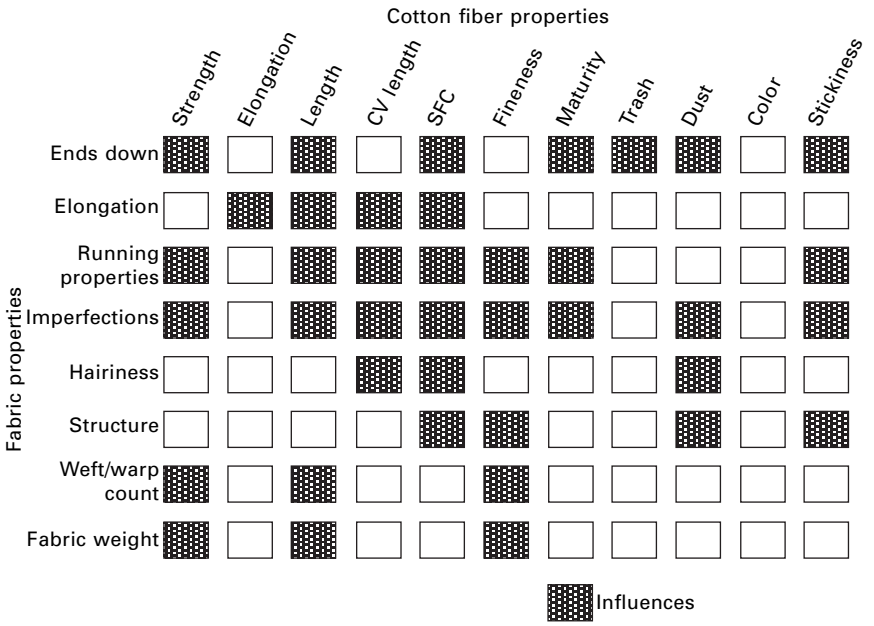
The introduction of a core yarn with specific properties like electromagnetic protection, antimicrobial properties, elastic properties (Gries 2004), stiffness, strength, etc., opens enormous options for functionality. It can be applied in all technologies with different formations: in ring spinning the core yarn is centered; in OE spinning the 'core' winds around the staple yarn. Careful selection of the yarn construction also helps to prevent undesired properties that might occur in later processing. For wrinkle-resistant apparel, where the specific finishing is applied, the construction of a stronger yarn prevents too early abrasion. Stronger yarns also may be required if enzymatic treatment is applied in finishing.

3.8 Functionality in three dimensions through weaving and knitting processes

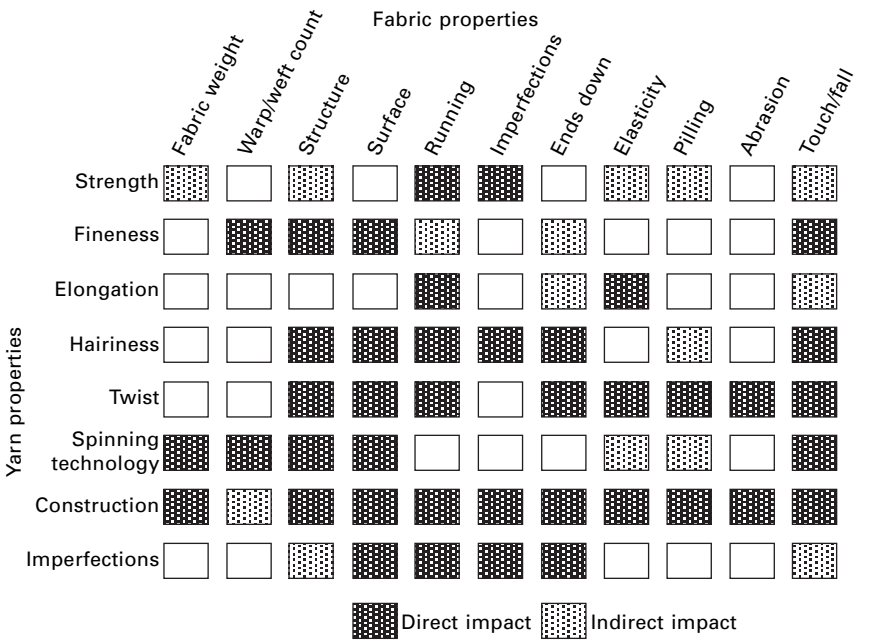
Even in fabric production, fiber properties like strength, length, short fiber content, fineness, dust and stickiness show an impact and may become prominent (see Fig. 3.18). Other factors affecting fabric production include inferior running properties in the weaving process, and imperfections or defects in the woven fabric. Some of these impacts are indirect, as they are embedded in the yarn (hairiness, imperfections and irregularity). With yarn construction and spinning technology some fiber properties can be influenced (see Fig. 3.19). Mainly natural fibers (cotton, wool) are treated with size, but also microfibers require reinforcement in the weaving process.

[6] The production costs may be higher than those of sizing

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3.18 Correlation matrix of cotton fiber properties and fabric properties. CV = uniformity, SFC = short fiber content. Ends down = broken yarns, weft/warp count = number of yarns per cm weft or warp.



3.19 Correlation matrix of yarn properties and fabric properties. Ends down = broken yarns, pilling = entanglements of loose fibers.

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3.8.1 Fabric constructions

Fabric construction has a high influence on function, specifically through the density and thickness of the fabric. Loose fabrics allow more air circulation and thereby better thermal regulation than dense fabrics. Dense fabrics provide protection against UV radiation and climatic influences (cold air and rain). Dense fabrics can be produced with high warp/weft density and specific weave types (see below). Application of elastic yarns provides stretch and bi-stretch fabrics with high flexibility allowing extreme mobility. Yarn counts for weft and warp influence the weight per m^2, the surface touch and air circulation. The higher the warp and weft count, the stiffer is the fabric, a property which is influenced additionally by the yarn construction (spinning technology, twist, plied yarn, core yarn, etc.). Therefore the fall of the fabric with low warp and weft count may be soft, but the touch of the surface can be perceived as rough, as individual yarns are detected by the skin sensors. If the yarn surface is treated accordingly in finishing, the fabric surface may also feel soft.

3.8.2 Weave types, patterns and colors

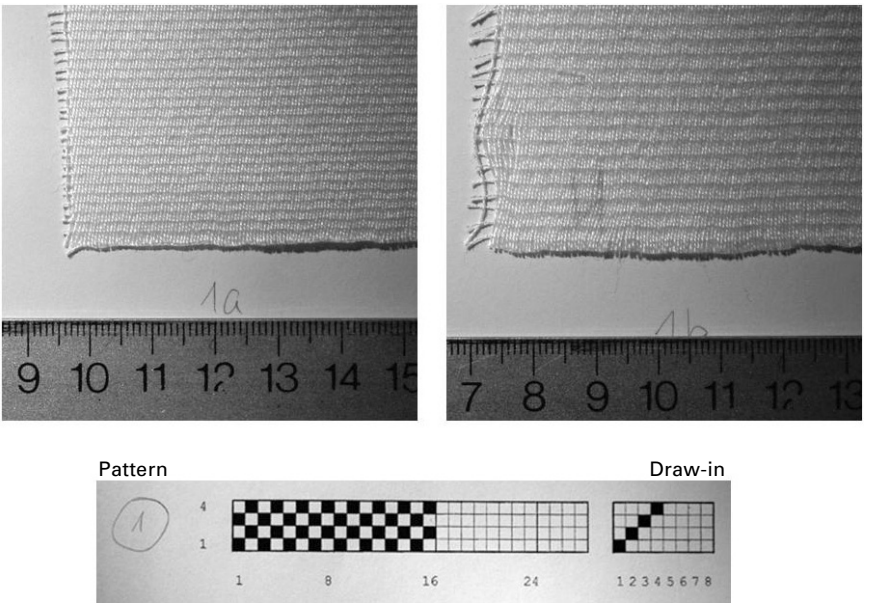
The weave type is defined by the crossings of warp and weft yarns. The weft count can be altered on the loom, while the warp count is set with warping. There are three main weave types: canvas, twill and satin. The oldest and simplest weave type is canvas, applied in the earliest historical hand weaving. The weave is defined in a pattern of crossings, whereby black squares mark crossing of the weft under the warp, and white squares mark crossing of the weft over the warp (see Fig. 3.20).

The canvas weave type follows the rule 1/1, with alternately one crossing over and one crossing under the warp yarn. A low warp and weft count, woven with canvas bonding as shown in Fig. 3.20, produces a light fabric with high air circulation and water penetration but lower fabric stability. The former properties are increased with a lower weft count, whereby the stability of the fabric has to be evaluated manually. Figure 3.21 gives an example of a twill weave, following the binding pattern 1/2, whereby the weave is shifted for one position with every weft insertion. Classic applications of twill are denim jeans, where two colors are applied to produce the typical color effect. Generally the warp is dyed with indigo blue, while the weft yarn is not dyed.

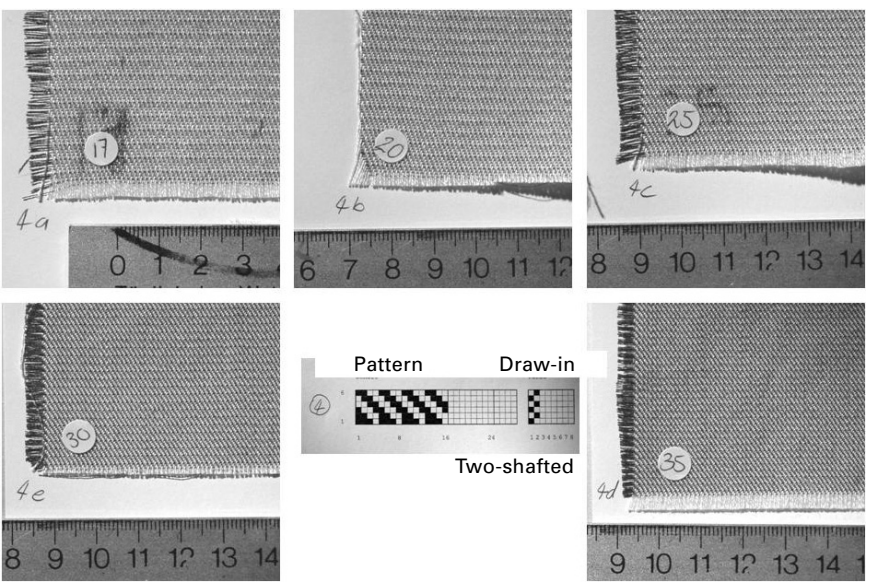
Figure 3.21 shows the effect of different weft counts from 17 to 30 per cm. Classical production uses pure cotton. In fashion application cotton fibers may be blended with polyester staple or elastane for weft and/or warp, the cotton warp being replaced by a filament yarn of polyester or polyamide.

The satin weave is the most dense package with one weft crossing under

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3.20 Canvas fabric with variations in weft counts: 6 (left) and 4 (right). The frame setup is based on a four-shaft sheddings.



3.21 Traditional twill fabric (denim) with two colors and variations in weft density: 17, 20, 25, 30 and 35 counts per cm. The frame setup is based on a two-shaft draw-in.

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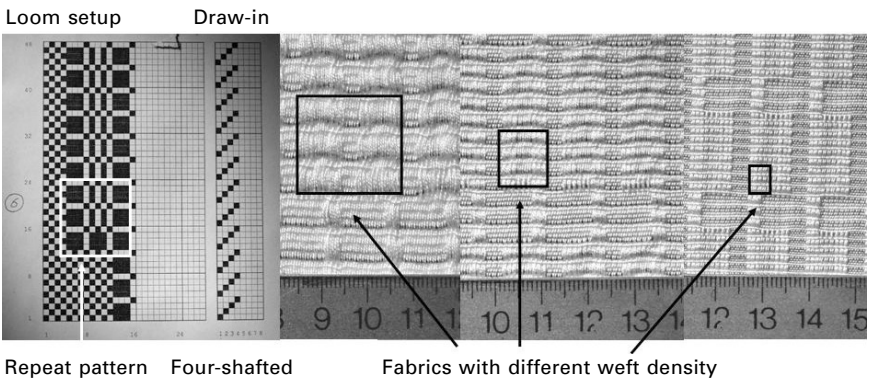
the warp followed by three or more crossings over the warp. In the next weft insertion the position is shifted. The surface of such a fabric feels smooth and soft and is characterized by many yarns in parallel, providing a typical luster. The dense packaging allows less air circulation, but provides better protection against UV radiation and water penetration.

Besides these basic weaves, a great variety of patterns can be designed, whereby the structure of the surface is influenced by the weave and color and other effects are set with weft yarns. Figure 3.22 shows a one-color structural pattern, whereby a part of the pattern is based on canvas weave. The variation in weft count changes not only the air penetration and fall of the fabric, but also the appearance of the pattern, as the weft yarns are harder to identify with increasing weft density.

On the right side of Fig. 3.23 a multicolor pattern with structural effects is shown. The pattern also includes a part with canvas weave. An additional effect is given with the three colors in weft yarn. The setup in Fig. 3.23 shows the arrangement for the desired pattern. The two variations in weft counts also show the limits of weft count (right side), where the pattern appears 'stressed' and uneven in the canvas part, compared to the left side with a flat and smooth canvas part.

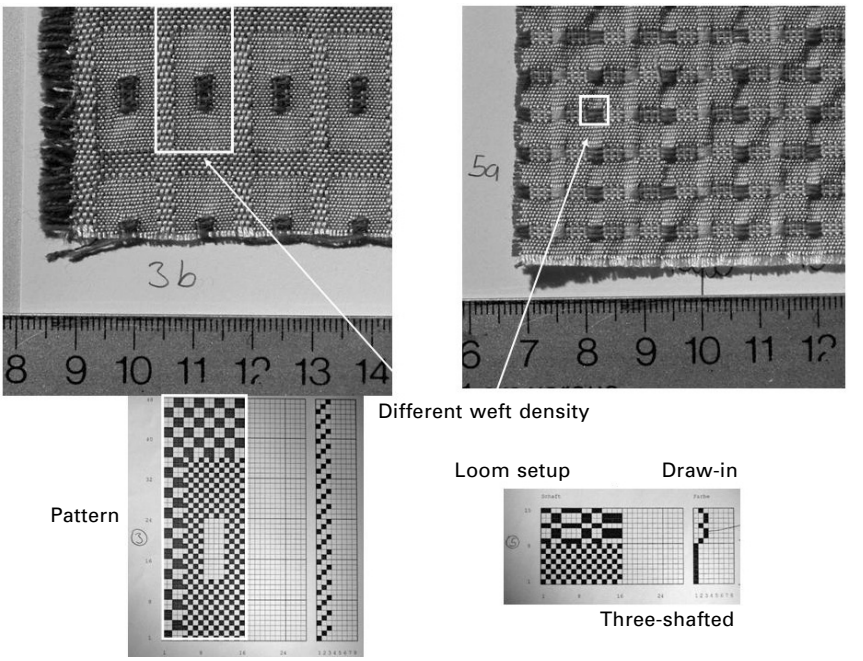
3.8.3 Weaving technology

Machinery for weaving has been developed with two aspects: to increase productivity and allow the creation of any textile design. A loom can produce a maximum width of fabric due to its geometry and a limited number of warp yarns. The density of the fabric is given according to the maximum number of needles arranged on the shafts of the equipment. To align all warp yarns in parallel the treaded yarns are arranged on multiple shafts (see Fig. 3.24).



3.22 Structural design pattern with canvas weave and one color. The three frames show three weft densities.

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3.23 Structural design pattern with canvas weave and three colors.

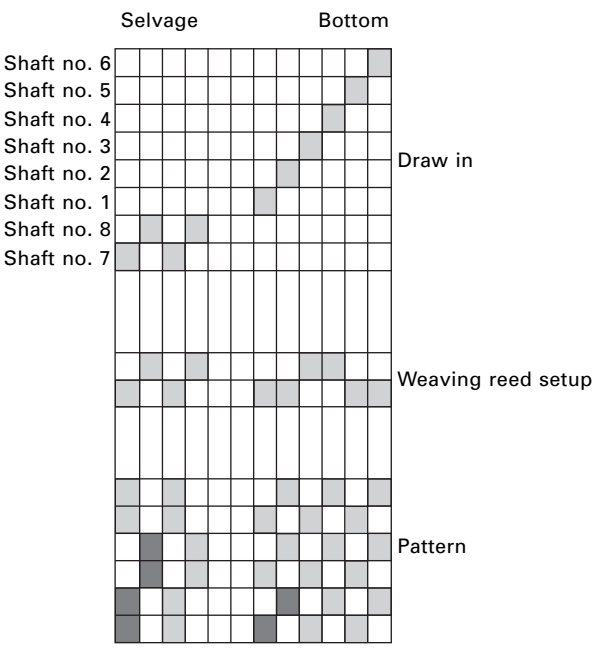


3.24 Warp yarn in weaving reeds, ready for knotting.

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Fabrics with a high warp density require more shafts. The large variation is given with up to 28 shafts and 12 different colors for the filling for very complex patterns. This setup includes restrictions for patterns and weaves because the warp yarns of one shaft are moving together, allowing the weft to slide in between two shaft positions. Consequently the arrangement of shafts has to follow the desired patterns.

All warp yarns are threaded through the needles, which are organized on different shafts, allowing the opening of a shed. By lifting the shafts with the corresponding warp yarns, the filling is injected through a shed. Consequently the warp yarns have to be organized in such a way on the different shafts that the desired weave can be accomplished. After each injection of the filling the ends of the weft are fixed in the selvage and the new weft is mechanically pressed against the woven fabric. Generally the selvage is formed with specific warp yarns, mainly of different fineness and a different weave type from in the bottom (see Fig. 3.25). A system of lamellae, through which each warp yarn is threaded, checks the warp and stops the machine if a warp yarn should break. The process of opening a shed, injecting the weft and subsequent beating up of the weft against the woven part is carried out up to 6600 times per minute for a rapier type and up to 14,000 per minute for an airjet type.



3.25 Setup and weaving reed for a canvas fabric (weave type 1/1). The selvage is formed in a different weave and color.

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A weaving machine is constructed for a maximum fabric width. The width can be smaller if fewer warp yarns are threaded. Fine fabrics are characterized by a high warp count per centimeter. Machinery types are more or less specialized for typical fabrics. The more complex patterns that are woven, the more shafts are necessary.

The oldest system is the shuttle loom, where the shuttle carries a length of packed weft yarn across the warp. After each insertion the weft is cut and the shuttle moves back to the start position for another insertion. After a certain number of insertions the shuttle has to be reloaded with a new weft yarn package. Weft insertion can be carried out with different systems. In projectile machines the weft is drawn from a fixed bobbin and transported with a projectile, which has to be stopped if the end of the fabric is reached, and the weft yarn is cut. The projectile is transported back to its original position to take up another weft for insertion. Rapier machinery performs weft transportation by means of two rapiers moving simultaneously from both ends of the machine to the center, attached on composite belts which are rolled and unrolled. The left rapier brings the weft to the middle where it is taken over by the right rapier and transported to the other end of the fabric. Rapier machinery is used for precise weaves, mainly in colored patterns.

Airjet machinery makes use of compressed air for the transportation of the weft yarn, whereby the yarn is driven in sections until it reaches the fabric's end. In the newest technology, the multiphase machine, weft insertion is performed simultaneously in four openings whereby the warp is arranged in a cylindrical form (instead of the flat types). Productivity of this system is very high (up to 5000 m/m/mim) specifically in types with insertion of two to four fillings at a time.

The choice of machinery follows product-related strategies like type of yarns, the fineness of the fabric, weave types and number of colors (Gunkel 2002). Other decisions concern maintenance, flexibility, quick exchange of beams, electronic support of settings and productivity. For complex weaves and colored fabrics a rapier type is appropriate, while simple, one-color fabrics need to be produced with high productivity.

3.8.4 Knitting processes and functionality

Wherever a certain elasticity is required, knitting is the first choice for fabric construction. Compared to woven fabrics, knits afford also higher wrinkle resistance but lower dimensional stability and bulging relaxation. In earlier days knits were limited to underwear and stockings, socks and pullovers. But with casual apparel like T-shirts and sweatshirts, knitting technology increased its share in apparel. Knits are specified in g/m^2, whereby fabrics from 50 g/m^2 up to 500 g/m^2 can be produced.

Natural fibers like linen and hemp require a lower speed in knitting and

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lower tension of the loops. Increased maintenance to remove dust from pectin on machinery is necessary. Fabrics with a high hemp or linen content have to be processed carefully to provide deformation. Further relaxation, washing and drying or fixation improve dimensional stability.

Knits can be produced on circular or flat knitting machinery as well as in 'fully fashioned' technology. The latter refers to flat knitting of fully fashioned pieces which are assembled seamless.

Circular knitting machinery produces fabrics in a tube form. Different fabric diameters require different machinery with a higher or lower number of needle systems in a circle. Unlike in weaving, the fabric density may not be changed on one machine. Table 3.35 gives data for two machines with individual setups for the two products. According to this strict mechanical arrangement each machine offers only small options for the size of the loop, set by yarn tension. Parallel stripes of different colors can be achieved by the setup of colored yarn cones. Knitting machinery is specialized for particular knitting patterns such as 'single jersey', 'interlock', 'adjour' or other knitting patterns. Their setup and processing are controlled by computers and sensors. Hence the variation in products (size and patterns) of a knitting plant consists of the different knitting systems available.

Only a small proportion of knitted goods is produced on flat knitting machines. 'Fully fashioned' and 'seamless' knits reduce expensive body shaping manufacture and waste production. They also contribute to higher wear comfort due to the lack of seams.

3.9 Chemical treatment for customer functionality

The chemical treatment is precisely adapted for specific fiber types. In pre-treatment (Section 3.9.1) fibers are individually prepared for the dyeing process (Section 3.9.2), where fiber-specific dyestuffs are applied. With the

Table 3.35 Examples of machinery settings and product specifications for two knitwear types in rib and single jersey with different yarn types

Machinery settings		
Machine	Terrot R 30 S	Monarch SX 3S
Diameter (in)	30	30
Density	E 15	E 28
Needles	2 × 1404	2640
Systems	30	90
Tension (cN)	2–2.5	5.6
Speed (rpm)	16.5	22
Product specifications		
Yarn fineness (tex (Nm, Ne))	25 (40, 24)	20 (50, 30)
Knitting pattern	Rib 1/1	Single jersey
Fabric weight (g/m^2)	150–160	115–120

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finishing processes (Section 3.9.3), dimensional stability is set, and surface properties and other characteristics are attributed. The desired properties are also described in Chapter 2.

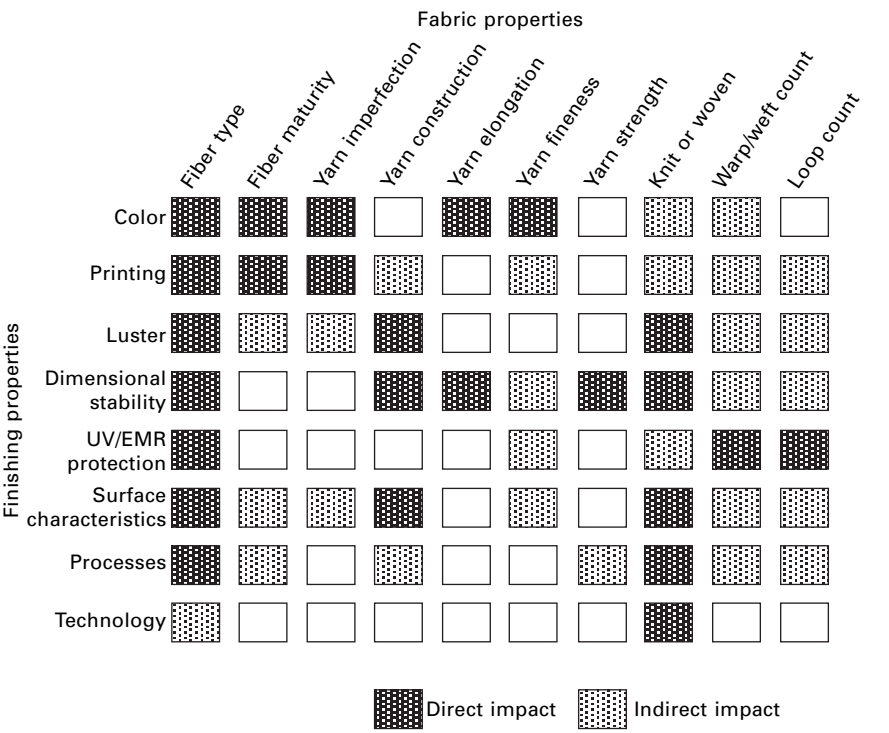
Depending on fiber and fabric types, specific process technology is applied: continuous or batch processing with open or skein fabrics. Individual process cycles and a large variety of formulas are applied. These aspects are specified for all chemical treatments in Section 3.9.4.

Figure 3.26 gives an overview of the main functional interrelations between finishing and fabric properties.

3.9.1 Pre-treatment

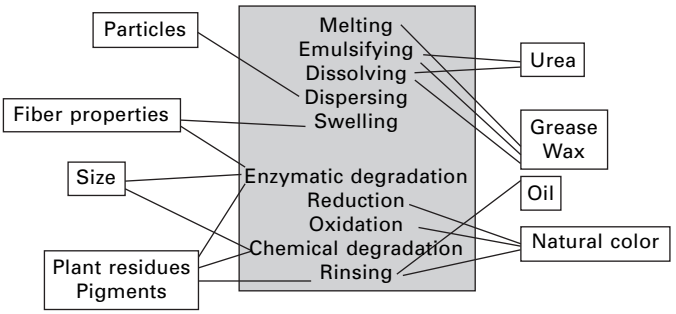
In pre-treatment the fabric is prepared for dyeing. An even surface and whiteness for dyestuff uptake is prepared. Several chemical principles have to be applied according to the nature of the residues or impurities.

As will be shown in the following section, natural fibers require an intense pre-treatment, as the imperfections have to be equalized (see Fig. 3.27). Different auxiliaries like emulsifying agents and dissolving agents as well



3.26 Correlation matrix of fabric properties and finishing properties. UV = ultraviolet, EMR = electromagnetic radiation.

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3.27 Principles of pre-treatment: the naturally existing impurities like particles, wax, etc., in natural fibers (white) are removed by means of different chemical–physical reaction types (center panel). Often several reaction types are available. Process auxiliaries like size and oils can be degraded with the same mechanisms. Fiber properties can be improved with swelling (mercerizing) and enzymatic treatment (removal of seed coat fragments).

as the pH conditions have to be adapted carefully in order to allow the main agent (enzymes, oxidation agent, etc.) to act efficiently. Output indicators are parameters in the waste water as well as in air (see Table 3.36). Sizing agents and knitting oils have to be washed out. They contribute to a high extent, up to 50%, to the effluent load of waste water.

Due to their common fiber base, cellulose fibers undergo the same changes in chemical wet processes and are mainly processed alike. The processes are generally developed for cotton. Some finishing processes like scouring of cotton add to the cleaning processes in ginning. Mercerizing of cotton enhances the luster and touch of a cotton fabric by swelling the fibers with alkali. Similar processes are carried out in washing of animal hair where grease, dung and urea are removed before spinning.

Singeing

In this process the surface of the open fabric is cleaned from protruding fibers by means of a flame. Cotton is singed in order to reduce the hairiness of the fabric, which is particularly critical if the fabric is thereafter printed. Similar results in low hairiness are gained when OE spinning or compact spinning technology is applied to the yarn.

Desizing and scouring

As most woven fabrics are sized for better weaving performance, the size coating has to be removed to allow liquids (bleaching agents, dyestuffs) to penetrate the yarns. Desizing takes place as a dissolving process, and

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Table 3.36 Suggestions for process improvement combined with average values under BAT

Process		Fiber	Substances to reduce or avoid	Load	Impacts
Scouring		Wool	Effluents with COD COD Organophosphorus compounds Synthetic pyrethroids Insect growth regulators Organochlorine	2–15 l/kg 150–500 g/kg	
Pre-treatment			Spinning lubricants Knitting oils Preparation agents Mineral oils PAH APEO		
	Wet treatment		COD	40–80 g/kg	
	Heat setting		C	10–16 g C/kg	Airborne
Desizing		Cotton	COD	20,000 mg O_2/l 95 g O_2/kg fabric	70% of pre-treatment
Bleaching	Sodium hypochlorite		AOX		Secondary reactions
	Combined hypochlorite /H_2O_2		90–100 ml Cl/l of AOX + 6 mg Cl/l (2nd bath)		
	Chlorite H_2O_2		AOX lower Complexing agents (stabilizers)		
Mercerizing			NaOH	40–50 g/l	
Dyeing			Dyes		Aquatic toxicity, metals, color

Abbreviations:
APEO = alkylphenol ethoxylate
AOX = adsorbable organic halogen compounds
Cl = chlorine
COD = chemical oxygen demand
PAH = polychlorinated aromatic hydrocarbons

the fabric has to be washed, rinsed and dried subsequently for removal of the sizing agent. The desizing agent is chosen to remove all varieties of sizing agents, because normally the formula of the applied size is unknown

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to the finisher. Desizing can be processed in a pad system by soaking the fabric in the solution and rolling it in the wet condition. Other options are exhaust technology on a jet. Sizes are removed by means of enzymes (for starch) or alkalis combined with tensides (for water-soluble sizes like carboxymethylcellulose (CMC), polyvinylalcohol (PVA) and polyacrylonitrile (PAN)). In integrated companies, recovery of the size is desirable, for reuse and reduction of the waste water load. Exhaust or pad technology can be applied (see Section 3.9.4, process technology). Careful adjustment of the pH is required for good results. The process time can be shortened if high-temperature processes are applied.

In the scouring process impurities like dust, plant parts, seed coat fragments of cotton, residual chemicals (pesticides, etc.) and other impurities are removed from the surface of cotton fibers. The fabric becomes more permeable for further processing. Depending upon the technology available (vessel, steamer or high temperature), time and pressure can be changed. Accordingly, processing time varies from a few minutes (high temperature technology) to 2 hours (vessel) (see Fig. 3.28). In alkaline condition auxiliaries like complexing, dispersing, wetting and emulating agents are applied, whereby the amount and type of impurities have to be taken into account. Higher amounts of alkali for faster processing may harm the fabric by causing catalytic damage (Meyer 2001).



3.28 Pre-treatment machinery as applied for an elastic cotton 'Manchester' fabric (case study E in Chapter 4).

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Many imperfections and failures become visible when a (cotton) fabric is finished: neps, thin and thick places, immature fibers, hairy or porous yarns represent only a selection. While neps and thick places can be well treated with enzymes to 'clean' the surface, thin places cannot be repaired in finishing.

A typical formula for scouring in continuous and batch processing is given in Table 3.37(a).

Bleaching

Especially light-colored cotton fabrics require an equal degree of whiteness, which is achieved by bleaching. In this process the natural pigments are destroyed and impurities are bleached for equal dyestuff uptake and corresponding equal color.

The earlier applied chlorinated agents have been replaced today by hydroperoxide for better environmental performance. Bleaching with sodium chlorite is no longer applied due to its harmful impacts on environment and machinery. The preferred processing is based on peroxide, which reduces the water contamination considerably. But some fibers like hemp require a double bleaching with at least one chlorinated bleaching agent. The bath gets additions of stabilizer, activators and washing agents. Neutralization of alkaline residues (mainly peroxy sodium bisulfite) is achieved with small amounts of acetic acid. Man-made fibers generally do not require bleaching.

Several formulas are developed for faster processing by combining two wet processes in one. Table 3.37(b) gives a typical recipe for scouring

Table 3.37 Formulas for (a) scouring and (b) combined scouring and bleaching processes in continuous and batch processing

	Process technology	
	Continuous	Batch
NaOH	20–80 g	20–80 g
Complexing agent	1–6 g	3–30 g
Tenside	5–6 g	5–30 g
Water	8–10 l	50 l

(a) Scouring

	Water-soluble size	General
NaOH 100%	10–20 g	40 g
Tenside	1.5–3 g	5 g
Complexing agent	2–4 g	2 g
Water	4–12 l	14 l
(Bleaching agent H_2O_2) 35%	15–25 ml	45 ml

(b) Scouring and bleaching

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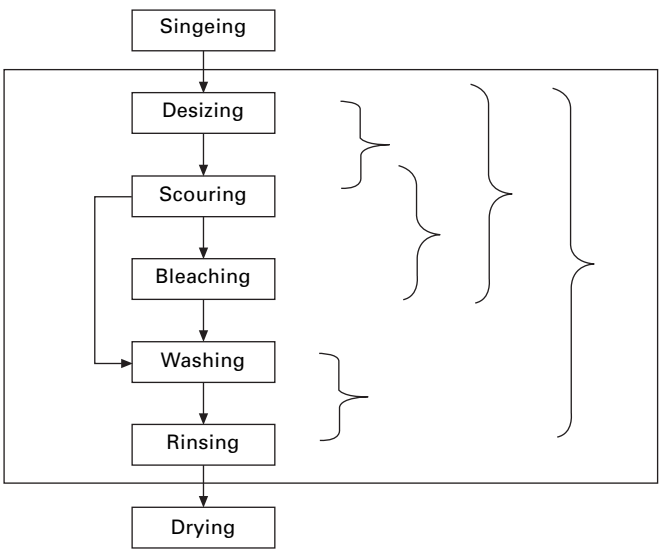
and combined desizing and scouring. There are countless variations for combinations of pre-treatment processes, as presented in Fig. 3.29. However, one must consider that incomplete removal of reaction components of the first process may disturb the succeeding processes, which may lower the quality of the fabric.

Mercerizing and alkali treatment

Only high quality cotton is mercerized for higher luster. The alkaline mercerizing agent (NaOH) is applied in exhaust or pad technology. Cotton fabrics are processed on a stentor under tension. The process is called alkali treatment if no tension is applied. The alkali moves into the cotton fiber and increases the inner pressure, which leads to a brilliant appearance. Subsequent careful washing follows with a dosage of acid, washing agent and a protective agent against chalk residues (corrosion). In a final process the fabric is dried on a convection dryer.

Wool and silk

Unlike cotton and other cellulose fabrics, wool and silk are 'finished' at least in some processes as fibers and additionally as fabrics. Wool scouring



3.29 Variations in pre-treatment of cotton fabrics. The brackets indicate the processes which can be combined. Quality aspects have to be considered because substances remaining from the preceding process may disturb the following chemical reactions and produce inferior quality. Washing and rinsing remove disturbing chemicals but are more costly and time consuming.

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and carbonizing are the first processes in fiber finishing. The fibers have to be cleaned intensively of natural fat, sweat, dung, manure, urea and other impurities the animal collected on its hair during its lifetime (Regensburger 2004). Washing is carried out in up to five baths with soda (Na_2CO_3) and non-ionic tensides, at pH 10. Temperature is low, 45–55°C, to prevent felting. The effluents are highly contaminated with organic load, a key indicator for wool finishing (Schäfer 2004).

Anti-felt treatment is a requirement for most applications. Because of the high impact by AOX (adsorbing organic halogens) in anti-felt treatment, environmentally friendly alternatives have been developed based on enzymes.

Wool fibers and fabrics can be bleached with ammonia bleaching, acid bleaching or integrated bleaching (a combination of oxidative and reductive processes). Temperature, time and pH are process parameters of the formulas. For economic production a short acid bleaching may be preferred, but for high quality products mainly integrated bleaching is applied.

Pre-treatment of silk fabrics consists of degumming (scouring) and bleaching processes. In the scouring process the silk glue (sericin) is removed. The protein-rich matter contributes to high organic contamination in the degumming effluents. This protein matter should be filtered, and the organic compound applied as a protein source in fertilizer, etc. Silk is bleached in a similar way to wool. A synthetic filling is added to the silk to compensate for the losses of sericin and provide a good drape of the fabric. Acrylic monomers or resins are exhausted to the yarn, where they react to polymers, which are embedded into the silk filament structure. This treatment also increases abrasion resistance and facilitates further processing.

Man-made fibers

The main man-made fibers are polyester (PET), polyamide (PA), polyacrylonitrile (PAN) and polyurethane (PU). There are hardly any impurities in man-made fiber woven fabrics, except for some auxiliaries from fiber formation. These are mainly monomer remains of the spinning (PET and PA), finish and size (PA and PET microfibers). In such cases a careful washing process is applied, combined with desizing of the mainly water-soluble sizes PVA and acrylate. Knits are generally contaminated with needle oils, which have to be removed in pre-treatment.

Polyacrylonitrile can be bleached with acid chlorite and PA can be processed with potassium chlorite, if necessary, while most other man-made fibers are not bleached. For PET and PAN, a thermal fixation is recommended before dyeing to increase dimensional stability. Also hydrofixation is applied in PA. If certain shiny properties are desired, alkali treatment produces a ‘silk’ character in luster and touch with PET. No optical brightener is necessary for PET and PAN.

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3.9.2 Dyeing and dyestuffs

Color properties are applied in either dyeing or printing. Dyeing follows the principle of application, fixation and rinsing, whereby a high fixation degree is aimed at. In printing the affinity of a pigment to the substrate is achieved by means of a binder. Immature cotton fibers do not take up dyestuff and produce white speckles, while porous yarns take up higher amounts of dyestuff and may create unevenness in color density. Essential for good reproduction of colors on natural fibers is an even white degree of the fabric, which is achieved by bleaching. Different dyestuff types and technologies can be applied (see Section 3.9.4).

Processing and formulas for dyeing are related to the fiber type and quality requirements. Process parameters are reaction type, availability of chemicals, time, temperature and pH. Up to 12 different colors can be applied in the printing sequence. Different affinity applies for plant fibers (cellulose based) and animal fibers (protein based).

Direct dyes were one of the first type to be applied for cellulose fibers as they are water soluble. More sophisticated dyestuffs are vat and sulfur dyes. The latest development is reactive dyes.

Wool can be dyed as fiber, yarn or fabric, though the dyeing of fibers is the most familiar. Wool fibers are dyed after pre-treatment and spun as colored fibers. Specific dyestuffs are developed for protein fibers, such as acid dyestuffs and metal complex dyestuffs as well as the more harmful chromatin dyestuffs. Reactive dyes have a share of only 10%. Alternative processing with metal-free dyestuffs for wool by means of oxidation at low temperatures has been developed by Vogler (2000). Due to its low fiber market share, there are no dyestuffs specifically developed for silk. Consequently wool dyestuffs are applied.

Most of the man-made fibers are dyed as a fabric, even if there are spun-dyed yarns available for some fibers like polyester (PET), polyacrylonitrile (PAN) and polyurethane (PU). Spin dyeing is easier to process, but may become uneconomic if only small batches of a specific color are produced. For economic reasons unspecialized production is preferable. Man-made fibers offer inferior affinity for dyestuffs in finishing processes and require specific fixation technologies. The physical and chemical properties of PET, PAN and PU fibers allow dyeing with dispersion dyestuffs. Acid dyes are applied in PET and PA and metal-complex dyestuffs in PA. PAN, the more demanding man-made fiber in terms of dyeability, can be dyed to a certain extent with alkaline dyestuffs in acid conditions.

If the fabric consists of a blend of fibers, mostly serial dyeing processes have to be applied in one or two baths, or with a different process technology, depending on the fiber types.

An overview on fiber types and dyestuffs is given in Table 3.38.

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Table 3.38 Correlation between fiber types and dyestuff types. Dark gray panels indicate good quality results, light gray limited quality results considering application and color fastness. Reactive and vat dyestuffs produce high quality with natural cellulose fibers. PP fibers show poor dyeability in finishing and should be spun dyed

Dyestuffs	Cotton, linen, flax	Regene-rated cellulose	PET	Wool, silk	PA	PAN
Reactive						
Dispersion						
Metal-complex						
Acid						
Alkaline						
Vat						
Direct						
Sulfur						

Color effects and fixation

The active color sensation is created by means of different intermolecular interaction types, the chromospheres. The principle is based on dislocating electrons within the molecule, which offers free sites in its atomic structures. In Azo dyes, with the typical N=N bonding between the aromatic rings, free electrons are responsible for the color expression. Quinone dyes are built from a typical arrangement of aromatic rings, along which the electrons are exchanged. Metal-complex dyes make use of the different heavy metals embedded for color expression. Free-moving electrons as radicals may also account for carcinogenic properties of substances. However, the effect has to be proven individually by means of clinical studies for each dyestuff.

Natural dyestuffs were selected historically because of their affinity to the fiber, although they did not allow a high exhaustion degree and good color fastness. The nature of synthetic dyestuff molecules was discovered only in 1862 and this started development on a large scale, first for indigo. Synthetic dyestuffs are designed for high affinity to the individual fiber and excellent color fastness by means of stereo effects and structure. Modern dyestuff may be transferred up to 97% on the fabric. Printing effluents consist of high concentrates of dyestuffs or pigments (up to 50% remains in the effluent).

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Direct or substantive dyes

This dyestuff type is one of the oldest known for cellulose fibers and provides an affinity to the substrate by adsorption. Therefore it can be processed in water solutions without auxiliaries, following chemical equation principles. The wet fastness has to be increased by means of auxiliaries.

Vat dyes and sulfur dyes

The more sophisticated vat and sulfur dyes, based on redox reactions, are not water soluble before they are oxygenated by means of a reducer. In this colorless form they are absorbed by the fiber and can be oxidized to their color expressive form. They show excellent color fastness with cellulose fibers and are much more expensive than reactive dyes.

Reactive dyes

These advanced dyestuffs were primarily developed for cellulose fibers, but later also for animal fibers (wool). They are water soluble and represent the only type reacting with a covalent binding with the substrate. This generates excellent exhaustion degrees, mainly applied in exhaust technology. Alkaline treatment is applied for fixation. Advanced fastness promotes their increasing market share.

Acid dyes

These dyestuffs are developed for protein fibers (wool and silk) and can also be applied for polyamides. They produce inferior color fastness compared to reactive or vat/sulfur dyes. Their acid groups form salt-like bonds with basic groups of the substrate. Different degrees of acidity (from acetic acid to sulfuric acid) are applied combined with an increasing amount of sodium sulfate (Glauber's salt). The more acidity the faster exhaustion is achieved. For processing, control of the pH is essential; values lower than pH 3 and higher than pH 7 may harm the fibers through hydrolysis of the protein structure.

Constant pH conditions are achieved by means of auxiliaries. The high amount of sodium sulfate ejected with the effluent produces a high environmental impact. Even if it is not precipitated, solid waste contributes to the environmental load.

Metal-complex dyes

Metal-complex dyes are developed from acid dyes to increase fastness, whereby the chemically bound metal (aluminum, chromium, nickel or cobalt)

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increases the color fastness and brilliance of the color. The most common wool dyestuffs are 1.2 metal-complex dyes, chromium dyes and acid dyes, each with a share of 25–30%.

Dispersion dyestuffs

Designed for specific affinity to polyester, dispersion dyes provide a high exhaustion degree of 90%, high fixation rate and good light and wet fastness. For uptake of dispersion dyestuff in exhaustion by PET fibers, the crystalline structure has to be opened by means of treatment with high temperature (HT) or so-called carriers. Also, pad dyeing technology can be applied at high temperature. While HT treatment requires more energy, carriers are mainly composed of AOX, substances harmful to the environment, whether in waste water or air.

Concerning eco-toxicity, dispersion dyestuffs degrade only slowly and may contribute to accumulation in the biosphere, due to their hydrophobic properties that facilitate accumulation in the fat tissues of organisms. As in the effluent, the dyestuff is often associated with dispersing agent which is hardly biodegradable, persistent contamination with a high oxygen demand (COD) in the effluent being measured. The latest developments in dyestuffs provide increased biological degradation abilities of the chemical.

Cationic (alkaline) dyes

These dyestuffs are characterized by amino groups with positive electrical loading, reacting with the acid groups of fibers. They were specifically developed for polyacrylonitrile, but still require delicate treatment. They can also be applied for cellulose fibers or acetate fibers.

Pigments

The chemical fixation of the printing dyestuff or pigment is achieved by means of specific binding agent, not by the dyestuff itself. The surface properties as well as the chemical structure of the individual fiber require specific chemical reaction types, in order to allow a permanent fixation of dyestuffs and pigments. The water-insoluble pigments can be organic or inorganic.

3.9.3 Finishing

In this last process chemical or mechanical treatment and processing is applied in order to complete and modify the surface properties of the fabric. For conventional apparel this means chemical fixation for dimensional stability, often combined with a softening or stiffening effect for a desired touch and

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fall. The treatment, often called sanforizing, is carried out in special drying equipment with three chambers, which can be heat-controlled individually. The fresh air input is heated by means of steam in heat exchange technology. Also, mechanical treatment is carried out, as an abrasion process for a soft and fluffy touch or as high-temperature pressure for luster of the surface.

Almost any desired properties can be added to the fabric in finishing. Man-made fibers are equipped with properties like flame retardance, wrinkle resistance, protection against EMR, electrical charge, etc. Natural wool fiber has inherent water-repellent and flame-retardant properties. Natural fibers are given water-repellent properties that are generally found only with man-made fibers. Further processing makes fabrics antimicrobial, UV protective, dust or oil repellent, etc. Each of these wet processes requires successive rinsing under acid conditions and washing, followed by a thermal fixation process on a stenter. Emerging technologies like plasma treatment and nanotechnology, providing new surface properties, will to a certain extent replace traditional finishing in the near future. Layers of different fabrics can be bonded by means of coating processes, opening countless combinations for surface design of fabrics.

Functions and process variations

Mostly there are alternatives for the application of a specific property. Thermal insulation can be increased by application of resins or coating, but also by mercerizing cotton fibers. Water uptake in man-made fibers can be increased through specific microfiber formation and by means of enzymatic treatment or mechanical abrasion of a fiber in finishing. Specifically designed fibers may include parts of the macromolecules with affinity for water uptake. UV absorption at the level of finishing can be increased with titanium dioxide as dyestuff, absorbing in the UV wavelength. Man-made fibers get this property just with a higher amount of delustering agent (titanium dioxide) in spinning, while natural fibers are dyed with UV-absorbing dyestuff. The density of the fabric construction in weaving or knitting also influences UV absorption properties. Bactericidal properties, often introduced to prevent skin irritations, can go as far as to kill all bacteria or to balance the number of bacteria.

Certain technically feasible functions should also be evaluated with common sense to see whether they are really necessary and favorable. This evaluation should also include considerations about environmental impacts and costs caused by the application.

Environmental impacts

To offer this large variety, finishing companies use multiple chemicals, which are all washed out in effluent to a higher or lower extent. When the fabric

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is dried after processing, unfixed chemicals transfer to the gas phase and contribute to airborne emissions, as do the incineration processes for energy production. Often an energy-consuming drying process is applied between subsequent wet processes, except for some defined wet-in-wet treatments.

3.9.4 Process technology

Wet process technology for finishing includes several aspects concerning the shape of the processed fabric, the treatment of separation of fabric and bath and the motion processes. Affinity of the dyestuff to the fabric and compatibility with processing is important. Table 3.39 gives an overview on fibers, processes, technology, and dyestuffs.

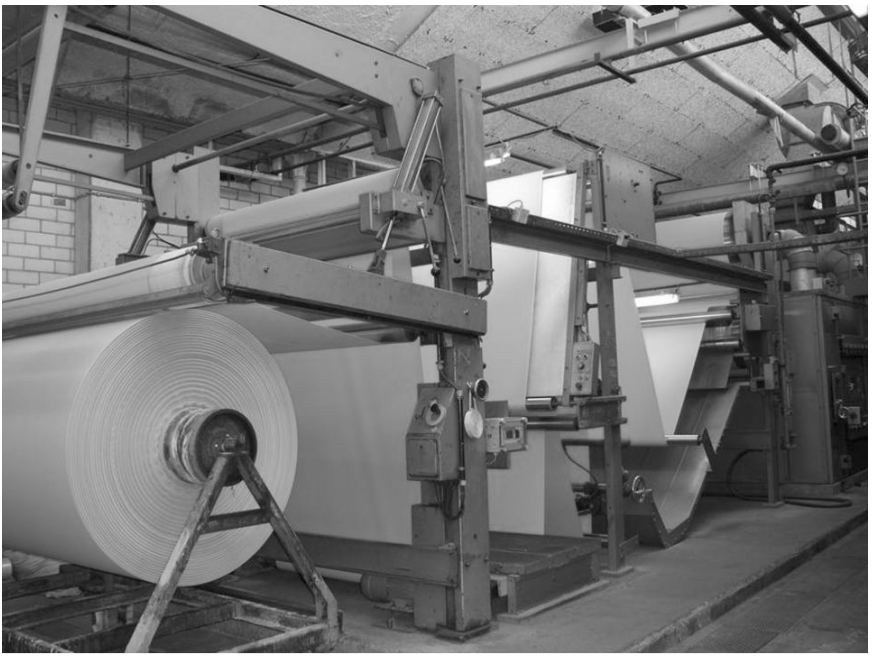
Processing is defined as continuous if one wet process leads continually to the next wet process, allowing a mix of process chemicals. It indicates a series of processes, e.g. impregnation, fixation, washing and rinsing is carried out in an ongoing processing sequence. Batch processing includes a separation process of bath and fabric, e.g. with a rolling unit or a drying process. In discontinuous processing the flow of processes can also be interrupted for relocation of the fabric (e.g. on a rotating roll for fixation).

A fabric can be 'open' (flat) processed or skein (knitwear, often as a tube). The processing of a fabric in skein is the older technology and exposes the fabric to higher tearing stress. An open fabric is transported under control over rotating cylinders or on stenters (see Fig. 3.30).

Table 3.39 Available dyestuffs, technologies and processing for different fibers. BAT in dyeing is performed on pad roll systems or at high temperature (HT)

Fiber	Dyestuff	Technology	Process
PET	Dispersion	Exhaust or pad steam	HT or carrier
	Reactive dyes?		HT or carrier
	Metal complex?		HT or carrier (pad)
PA	Acid dyes	Exhaust and pad steam	Discontinuous/continuous
	Metal complex		Batch
	Dispersion	Exhaust	Batch
		Exhaust	
PAN	Dispersion	Exhaust and pad steam	Continuous
Wool and silk	Acid dyes	Exhaust	Discontinuous
	Metal complex	Exhaust	Discontinuous
	Reactive	Exhaust	Discontinuous
Cellulose	Reactive dyes	Exhaust	Discontinuous
	Direct dyes	Pad roll	Semi-continuous (continuous)
	Vat dyes and sulfur dyes	Exhaust	Discontinuous
		Pad roll	Continuous
		Exhaust	Discontinuous
		Pad steam or pad roll	Continuous or semi-continuous

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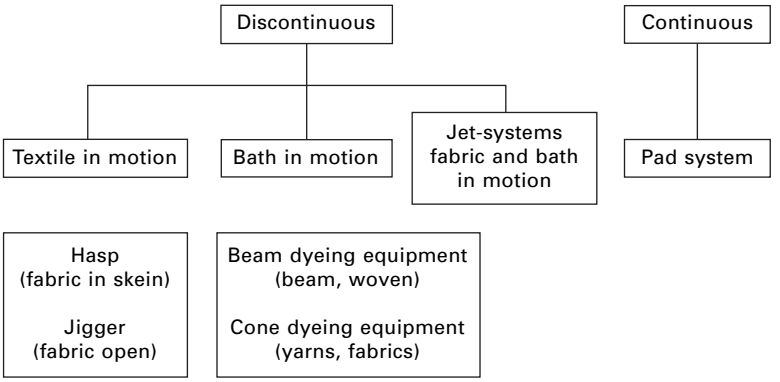
3.30 Open processing of a cold padded fabric. After the fixation of the applied dyestuff on the rotating roll (in front), the fabric is conveyed to a washing and rinsing process for removal of excess dyestuff.

Wet processing equipment is constructed with the principle of a so-called machine, where the fabric is in motion (hasp or jet), or with the principle of an apparatus, where the bath is in motion, as in high temperature (HT) apparatus or a jigger machine (both for flat processing). The chemical reaction type with this equipment is exhaustion, a reaction towards the chemical balance of the available educts. A newer development is the pad system for open application. A systematic overview is given in Fig. 3.31. Man-made fibers require higher temperatures in dyeing processes.

Pre-treatment and washing equipment

Machines for continuous technology consist of several compartments, each separated by squeezing rolls to separate baths from fabric before the latter is moved to the next compartment. Each compartment can be heated and fed with water and auxiliaries individually. Auxiliaries like tensides, complexing agents, emulsifiers, etc., are supplied from a dosage system. The fabric can be processed open or in skein. When the fabric has traversed all compartments, it is fed to the drying device. For the next process flow all the baths are

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3.31 Variations in finishing technology with different processing equipment (discontinuous, batch) and different fabric configurations (open and skein).

pumped from one position to the next in the opposite direction to the fabric movement. Thus, fresh water is fed to the empty compartment and the most heavily loaded rinsing water is ejected.

Washing and rinsing processes can be carried out in batch technology in a jet, whereby the rinsing water is fed in batches to the fabric.

Scouring, mercerizing, bleaching, washing or dyeing as well as carbonizing of wool (see 'Wool and silk' on pages 209–10) can be processed with the same technology.

Drying technology

Conventional drying is processed with open fabrics along plane, closed heating equipment with several chambers. The heating temperature of the individual chambers as well as the velocity of the fabric through the chambers can be adapted. Often a stenter with clamps and chains for control of shrinking is installed.

For extreme high temperatures, as required for fixation of man-made fibers, steam-heated equipment is the choice. In this equipment several densely packed cylinders convey the fabric between the elements through the equipment. Heat and speed control are crucial in process technology of modern fibers.

Process technology for exhaust reaction

The exhaustion principle works with the reaction of chemical educts towards a balance. Such reactions are controlled by time and temperature, often by means of auxiliaries for retardation, acceleration and pH buffering. Their base is a bath, wherein the fabric is exposed to the chemicals in such a way

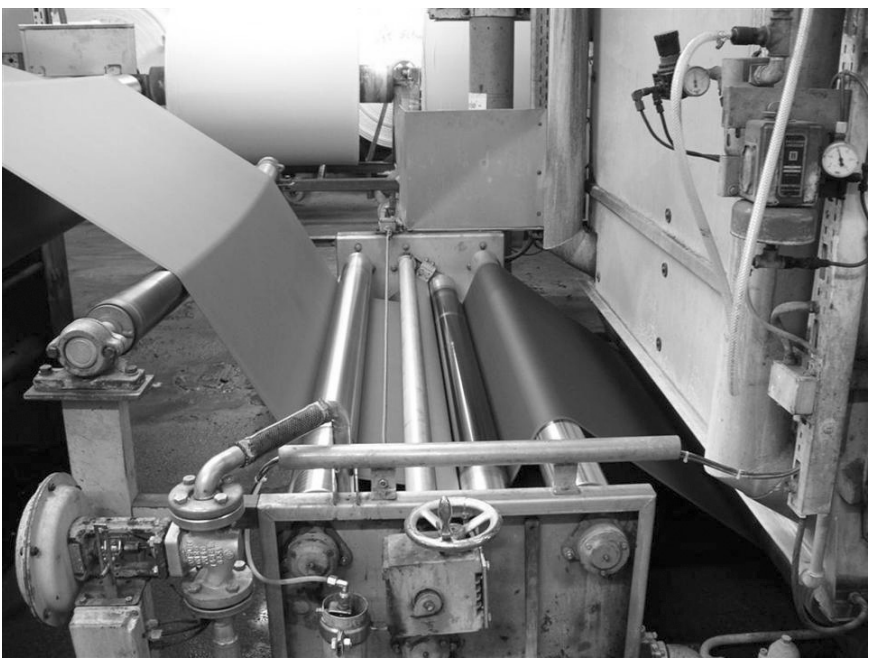
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that an equal uptake is ensured. All exhaust processes can be carried out in hasp, jet, jigger or HT apparatus. Specific beam dyeing equipment is applied for dyeing processes of rolled (beamed) fabrics, whereby the bath is pumped with constant pressure through the layers of the fabric.

Raw fabrics of polyester are dyed in jets with HT technology or at lower temperatures by means of a fixation auxiliary, consisting of AOX. Processing requires acid conditions (pH 4–5), set by additional acetic acid or formic acid. With a process temperature of 125–135°C additives like aliphatic carbon ester, a combination of ethoxylate or alcohol, esters or ketones with emulating agents are necessary to prevent too high absorption.

Pad systems

In pad systems the fabric is carried between rotating rolls into a compartment with a highly concentrated dyestuff solution (see Fig. 3.32). The excess dyestuff is squeezed between the next rolls. In continuous processing, the dyestuff is fixed and washed out and the fabric is dried (pad steam or pad jig). In a discontinuous process the fabric is rolled on a rotating cylinder



3.32 Pad system for wet processes. The fabric (left side) is submerged into the dyestuff chamber and quenched between two cylinders. The same technology can be applied also for mercerizing and bleaching.

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for fixation in cold conditions overnight (pad roll). With a foil the moisture content is kept constant and the rotation allows equal fixation throughout the roll (Fig. 3.33). Washing and drying follow next morning.

The pad-roll processing can also be applied with reactive dyes, whereby the fast hydrolysis of the dyestuff must be prevented. A comparison of process technologies of exhaust and pad is given in Table 3.40.

Printing technology

The main available systems are gravure printing and relief printing, the latter comprising transfer printing, screen printing and inkjet technology. The machinery is equipped with either rotation or flat application systems.

In transfer printing the pattern is produced by engraving on a copper plate. Screen printing is a photochemical process. For each color a template is prepared, whereon the negative pattern is photochemically fixed. The fixed area becomes waterproof, while the unfixed parts are washed out. In the



3.33 Pad cold patch treatment, an energy-efficient treatment for dyestuff development, simply by rotation overnight.

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Table 3.40 Comparison of pad and exhaust technology in finishing. Pad systems provide environmental advantages as they require less water and less process energy and produce lower amounts of effluents

	Exhaust system	Pad system
Dyestuff	Dissolved	Highly concentrated
Bath–fabric ratio	5–20	4
Application	In solution	Coating
Process	Diffusion (time/temperature equilibration)	Dipping and squeezing
Affinity to substrate	Necessary	Not necessary
Time	Hours	Seconds
Allocation on fabric	Exhaust	Surface position at random
Effluent	Yes	Small amounts

printing process paste is pressed through these areas, building up the color. A new technology, offering endless patterns, is computer-controlled inkjet printing. The technology is developed from computer print technology.

For impregnation so-called print pastes are applied as a formula of dyestuff (or pigments), thickener, binder and other agents for dilution, dispersing, cauterization, etc. The processes are serial as follows: local application of printing paste by impregnating, followed by thermal fixation, washing and rinsing.

In flat, rotary and roll printing the printing paste is applied through a perforated screen or roll, representing the pattern. In flat printing the fabric remains in the same position, while different racks with individual colors are impregnated. In rotary and roll printing the paste is applied by means of rolls. The rotary system consists of 8–12 serial rolls with perforated surface, which are fed with the corresponding printing paste. The fabric is moved underneath the rotary system.

Finishing technology for wet processes

Chemical finishing is processed open in exhaust or pad technology, depending on the emission characteristics of the chemical. The chemical affinity with the selected substrates (fiber types) requires a large variety of auxiliaries and formulas in wet processing. Wet processes follow the principle of thermodynamics by reducing process time with increasing temperature. For efficiency reasons reduced process time may be favored, but energy consumption increases. Also the temperature scale is limited by the fiber substrate, which may undergo undesired changes if treated with too high temperatures. Particularly man-made fibers including elastic fibers are delicate. Application is followed by fixation and rinsing.

Shrink resistance is the most important property for the customer. It is

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achieved by the application of water or steam followed by fixation with pressure. With the Sanfor-Plus label this property is achieved by means of resin or urea application. A further care property is wrinkle resistance by application of resins or ammonia (as with the Sanfor-Set label). For dimensional stability, cross linking with resins is required, fixed on a stenter, often as a 'Monoforized' labeled process. Water repellency, another market demand, is achieved with fluoropolymers or silicon treatment.

Softening effects are generated by means of waxes and fat- or water-soluble softeners, according to the desired permanent or impermanent effect. Application of properties to delicate man-made fibers also requires fixation, whereby the fabric is exposed to fiber-specific high temperatures for a very short time, between 10 and 50 seconds. With processes like steaming, ironing or drying, permanent fixation on the surface is achieved.

Thermo-mechanical finishing technology

Mechanical finishing of the surface is applied in calenders by means of abrasive paper, brushes or metallic needles. Thereby the fabric is pulled between rotating cylinders, which are equipped with the abrasive surface. With such mechanical surface treatment the fabric is partially disoriented by isolating individual fibers out of the weave in order to produce a hairy surface. Heated calender equipment is the choice for a (not permanent) luster of the surface, in which the impact can be increased by counter-rotation of the rolls.

Physical treatments, like ionization for antistatic treatment, are processed in closed chambers. Also nanotechnologies with specific gas atmospheres are applied (Fischer 2004, Stegmaier 2004).

Inspection, storage and packaging

A visual inspection of all finished fabrics is carried out after processing. The fabrics are rolled over an illuminated screen and are inspected by employees. Fabric inspection by the human eye cannot yet be replaced by an appropriate machine inspection.

In modern companies the inspected fabrics are wrapped on roll by packaging systems, whereby an identification code is applied. This enables easy handling in storage (see Fig. 3.34) and for transportation to the clients.

3.10 Functionality in product development

Together with the choice of a fabric, the style, cut and three-dimensional shaping of the apparel is constructed. In product development, functions from fabric and cut meet.

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3.34 Fabric storage after finishing.

In order to provide apparel with appropriate function a detailed analysis is necessary by defining apparel segments and important and optional functions, as Paulitsch (2002) and Arretz (2002) indicate for environmentally friendly textiles.

Table 3.31 on pages 182–3 shows what functions should be addressed in developing outdoor apparel, workwear, children's wear, sportswear, underwear, outerwear or specific styles such as formal or casual dresses. According to the activities mentioned above, the functional aspects of mechanical protection, thermal insulation and regulation, mobility and water regulation as well as specific risk protection (fire, ultraviolet radiation and electromagnetic compatibility) are evaluated (Klaus 2000, Blum 2000). Functionality is set mainly in marketing and merchandising (see Chapter 5).

3.10.1 Functionality in cut

For manufacturing, a designed style is transferred into appropriate fit for the consumer according to functionality. Apparel should be designed for a specific purpose, taking into account the required freedom of movement. Strong body movements as in hard physical work require even more loose fit and/or elasticity than extended movements, as are allowed for in children's

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clothes, sportswear, etc. Body positions such as sitting in offices or airplanes should be facilitated, as well as long periods of remaining in an upright position as experienced by personnel in shops or in industry. Babies' and children's wear and women's tights require appropriate properties. Specific attention is called to closures such as zippers, buttons, snaps, etc., allowing easy dressing and undressing. Selected linings, fixings and stiffeners may also be applied for certain functions and for a perfect and long-lasting fit of loose fabrics. The care comfort determines these accessories of the apparel. It is evident that such evaluations contribute to higher cost.

3.10.2 Functionality of protection

The basic functions provided by clothing are driven by human needs for protection against climatic influences (cold, heat, rain, wind, etc.). Some working environments call for increased protection functions, typically in industry, but also in civil protection functions like fire protection. Improved moisture regulation may be required if heavy physical work is carried out. Often a combination of high mechanical or thermal protection with extreme mobility is required, asking for innovative solutions.

People now in many ways lack appropriate body movement in their work and search for compensation through sports activities, where specific functions of water regulation need to be met. Due to the partial loss of the ozone layer, additional protection against UV becomes necessary, particularly for children and persons with outdoor activities where they are exposed to strong UV radiation. People's poor perception of fire risks combined with a sometimes reckless behavior with fire lead to regulations for fire-protection functionality. Fast-drying and stain-repelling properties can be achieved with water regulation functions and oil protection regulation, respectively. Often functions for extreme applications are transferred as options into conventional apparel (Fig. 3.35).

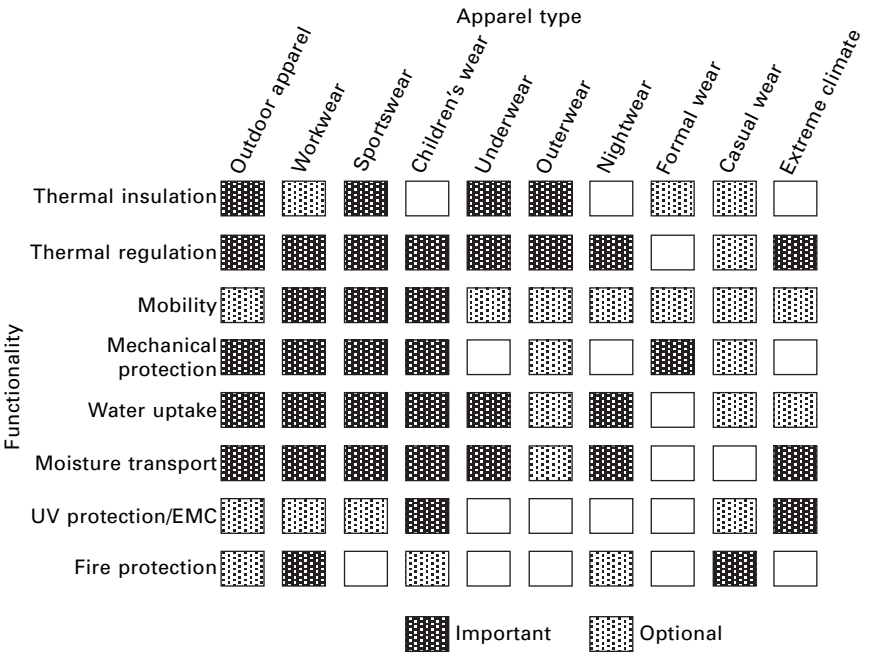
Fashion as a function for self-profiling, and intelligent textiles for specific medical functions or personal identification as part of security systems, etc., represent the two extremes of functionality: neither will be discussed here. Care properties are not considered as functionality, but they cannot strictly be distinguished. The required functions have to be defined in product development on the level of apparel production.

As shown in the previous chapters, there are several options to build up the properties in the fabric which provide these functions.

3.11 The origin of best available technology (BAT)

Best available technology (BAT) has been defined by EC Directive 96/61 on Integrated Pollution Prevention and Control (IPPC) (see also Section 1.3.2

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3.35 Correlation matrix of functionality and apparel type. UV = ultraviolet, EMC = electromagnetic compatibility.

in Chapter 1) as favorable technology to apply for the lowest environmental impacts. A large document, the BREFs, has been prepared for the industry.[7] This section presents an evaluation of the BREF document and adds contributions of missing aspects along the value-added chain, together with a summary of the BAT in the BREF document.

3.11.1 Evaluation of the BREF for textiles

In COST Action 628 a Task Force BAT evaluated the large document by indicating some areas for improvement. The three main evaluation statements (Tobler *et al*. 2003) are given below.

Who will be working with the BREF document?

The BREF document is presented as a large textbook, maybe suited for students or small and medium enterprises (SME) but hardly for large companies. But its primary use is for the authorities in order to control and advise companies

[7] http://www.sepa.org.uk/ppc/brefs/

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all over Europe. The Task Force BAT found the document difficult to apply in a comparable manner by authorities for several reasons:

- Different legislations in individual nations
- Different knowledge of authorities (as they are not textile experts)
- Different cultures of environmental authorities (emission oriented) and the textile industry (product, process and market oriented).

On the other hand, the European textile industry suffers dramatically under declining market prices because of cheap imports of textiles from countries with no or with very low environmental regulations. Consequently an additional control will threaten the European textile industry. If BAT is to be implemented in Europe import regulations, based on product declarations, should be established and regular inspections of hazardous substances should be carried out. A streamlined and leveled BAT document together with an environmental product declaration (EPD) according to ISO or a textile index would be suitable instruments for controls.

3.11.2 Missing parts

Even though the document is quite large, some aspects are missing. Aspects of major concern for the textile industry, identified by the Task Force, are the following:

- Life cycle perspective
- Balance of fiber-based information (adequate representation of the European textile industry)
- Adaptation of finishing with use phase
- Practical advice on environmental load
- Social impacts
- Research and research institutes
- Economics
- Legislation.

A life cycle perspective is absolutely necessary for product development, as optimization has to be achieved from an economic and quality standpoint. The main focus of BAT lies in finishing. However, such processes may not be considered without relation to the materials, yarn manufacture, knitting and weaving. The poor communication along the value-added chain of textiles has its origins many years ago. Although information technology has since made much progress, the communication, based on technical specifications for adaptation of processes, has not improved. In a life cycle perspective not only production and waste treatment but optimization of function, transportation and lifetime duration will be as important as the selection of the right material and reduction of mixed materials.

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Such issues are not addressed by the BAT document. If BAT is applied in the present form, we have to expect mistakes when implemented by authorities. These mistakes will prove a severe threat to the textile industry in Europe.

A further aspect connected with the life cycle perspective is the adaptation of finishing with use phase. We would like to emphasize this point as it is of major concern for the consumer. Environmental aspects associated with care of textiles are considerable and exceed the impacts of finishing. On the other hand certain properties and standards in finishing have to be achieved in order to allow an appropriate lifetime duration of the textiles in the use phase. The BREF document misses some auxiliaries that are presently applied in finishing.

The present draft excites the idea that wool is a dominant fiber in Europe. On the other hand information on fibers like hemp and linen is missing. If the book is to be applied by authorities, it should cover all raw materials presently manufactured in Europe. A balance of fiber-based information should be provided.

Considering the aim of sustainable development, companies should not foster a maximization of ecological aspects but should aim at optimizing economic, ecological and social aspects. The social impacts, mainly caused by parts of the value-added chain outside Europe, are considerable and preferably taken up by the media. Therefore the image of the textile industry could be worsened if they are not given appropriate and accurate advice.

For improvements in the industry, practical advice on environmental load should be provided. Otherwise, BAT could be considered just as new legislation with the aim of weakening the already suffering European textile industry. Task Force members presented a booklet with such information elaborated for a big company. However, small and medium-sized enterprises cannot afford to generate such information. Other existing systems, like Eco-tex 100, Eco-tex 1000 and the EU label, were evaluated. While the Eco-tex 100 health-based label is widely accepted, Eco-tex 1000 as an environmental system is only poorly applied. ISO 14000 is based on legal compliance, varying for each nation (see legislation). The EU label does not yet show a successful entry to the market. In some countries, benchmarking in specific branches is performed, based on comparable key figures. Textile specifications have been elaborated for individual products. Life cycle-based environmental product declaration (EPD) according to ISO is not practiced by the textile industry. COST Action 628 itself aims to create an environmental index for textiles. None of these systems can be considered as a sufficient, holistic and streamlined instrument, although there is a strong need for such guidelines.

All these aspects can be met by industry's own research and/or cooperation with research institutes.

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The ever-changing market forces the industry to respond very quickly. Consequently processes and technology change from one season to the next. New investments can be made only if they are in the focus of further development. Therefore economy associated with process technology is an essential factor. It would be only fair to give an idea what the costs of BAT would be. Because of the differences in values such estimations must be given on a national level.

As legislation is different for each nation, all regulation-based environmental improvements (like ISO 14000, but also Eco-tex 1000) do not allow proper competition between companies since the limits and requirements are different.

3.11.3 Definition of BAT

The term 'best available technology' seems difficult to define and even more difficult to apply. 'Best applicable technology' would meet the expectations better.

BAT is not independent of product quality and must therefore be adapted in each case. It may, however, provide guidelines for permits and should include technology, processes and chemistry as well as recommendations (advice at the end of each chapter). Valuable additions would be:

- FAQ (Frequently Asked Questions) in the margins, where appropriate
- Practical guidelines for the intended user
- Process tree with available techniques that are product or production related
- Tables giving correlation between the size of the plant and the most economic technique for production
- Efficiency, toxicity and cost of dyestuffs per m^2. (responsibility of the supplier).

3.12 Best practice in cotton growing and ginning

Cotton growing may be the most critical issue in terms of environment (see also Chapters 2 and 4). As cotton is a 'cash crop' it is often grown in areas that do not qualify for the term sustainable agriculture (according to OECD indicators). Often cotton growing for exports is in competition to production for the domestic markets. Many aspects of cotton growing are highly influenced by policy. For BAT the following properties have to be considered individually and seriously:

- Local pest and pesticide management
- Loss of urban primary vegetation in a local area
- Reduction or gain of CO_2 fixation compared to primary vegetation

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- Production of barren fields (salinization, sterilization, lack of organic matter and minerals, soil structure, etc.)
- Loss of area for domestic food production
- Annual loss of groundwater (due to irrigation).

From our research in the USA we can make a contribution concerning irrigation systems (see also Chapter 2). In a first study BAT of three irrigation practices was evaluated also with an LCA study (see Chapter 4). The adapted low energy precision application (LEPA), often called pivot system, can generally be defined as BAT. Investigations on water conservation and pesticide management carried out by NGOs (WWW 2002) are not correlated to cotton fiber quality.

3.12.1 Water management (irrigation systems)

Some of the major production problems in the Texas High Plains are a short growing season, soil erosion, sand and hail damage by strong winds, wilt diseases, and cool temperatures during the boll maturation period. Another important area of concern is the declining water supply caused by the declining water table of the Ogallala aquifer, which is an important groundwater source for the Texas High Plains, due to overexploitation (Terrell and Johnson 1999). This of course leads to a rapid rise in irrigation costs through more efficient but also more expensive irrigation systems.

Cotton in the Texas High Plains is either dryland (rain grown, no irrigation) or irrigated by one of the common irrigation systems: furrow irrigation, low energy precision application (LEPA) or drip irrigation. The reasons for not irrigating the crop include sufficient natural rainfall, lack of water through wells (for example, due to the declining water table) or the high costs of installing an irrigation system or drilling a deeper well.

With furrow irrigation water is applied by flooding the ditches between the rows made by tillage implements (Fig. 3.36). LEPA uses drop tubes extending down from the pipeline to apply water at low pressure on – or only a few inches above – the ground (Fig. 3.37). Drip irrigation is a method used to place irrigation water near plants' roots through pipes or tubes on or under the surface. This reduces water evaporation and runoff and keeps moisture in the soil within an optimum range (Fig. 3.38). (Source: Simone Schaerer, ETH Master Thesis)

3.12.2 Water management and its consequences for fiber quality (conventional and genetically modified)

The second study focuses on fiber quality harvested from four different irrigation systems: dryland, row (furrow) irrigation, drip irrigation and pivot

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3.36 Furrow (row) irrigation requires high amounts of water due to the high evaporation rate in the semi-arid climate.



3.37 LEPA (pivot) system for irrigation of cotton plants and application of liquid agrochemicals.

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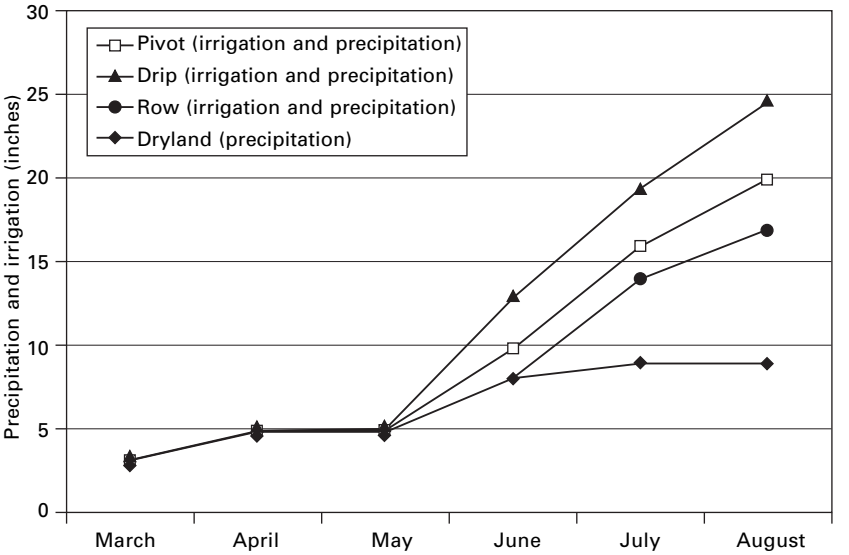
3.38 Drip irrigation provides the plants at their roots with the necessary moisture. Agrochemicals which are taken up by the roots can be added to the irrigation water. The system can also be buried in the soil as a permanent but expensive installation.

(LEPA) irrigation in the same area. An additional parameter was investigated in the variation of genetically modified cotton (GMO) and conventional cotton of HS26, a commonly grown variety in the area. Quality measurements, based on individual bales, were carried out on High Volume Instrument (HVI) IV equipment with 10 replications from different positions within the bale. The amounts of water available to the plants as precipitation and irrigation are given in Fig. 3.39.

All examined fiber properties showed significant variations with the irrigation systems. Apart from micronaire, all measured fiber properties of pivot and drip irrigated cotton were between the mostly inferior properties of dryland cultivation and mostly superior properties of row irrigation. Strength and micronaire throughout all irrigation systems are inferior to the USDA measured values of cotton fibers from Lubbock (2002 strength average added up to 28.8 g/tex and micronaire average to 4.3; in 2003 strength average was 29.1 g/tex and micronaire average 4.4).

In dryland cultivation systems, there is no artificial irrigation; plants get only water from natural precipitation. Cotton plants under dryland conditions received an amount of water of approximately 9 inches, which was less than half of the water volume given to the three irrigated crops. Probably poor water supply during root development (planting date 6 June, 4.1 inches of

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3.39 Water management (irrigation and precipitation of the four irrigation systems) in the Texas High Plains (see Figs 3.36–3.38).

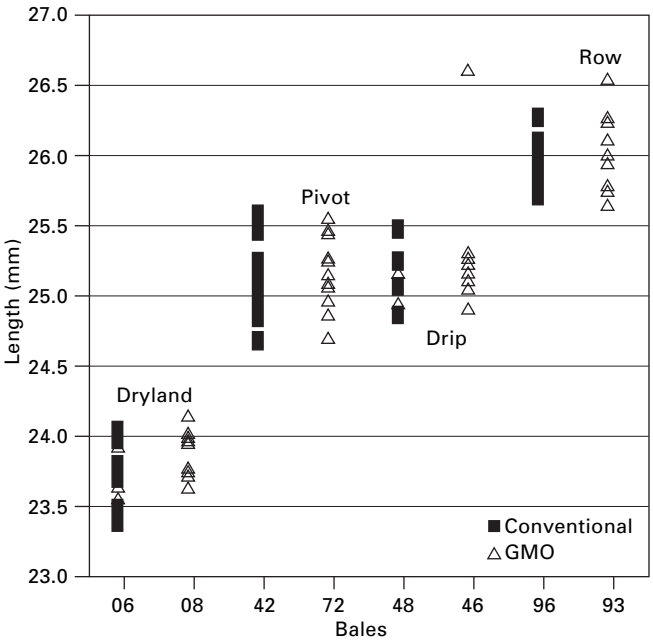
water from June to August, see Fig. 3.39) can lead to inferior cotton fibers. The conclusion we draw from this study is that low quality parameter properties are related to the amount of irrigation water.

As shown in Figs 3.40 and 3.41, cotton of dryland cultivation had the shortest (23.25–24.25 mm) and weakest (21.5–24.5 g/tex) fibers, with the lowest uniformity (79–80.6%) and consequently the biggest short fiber index values (20–24.5). According to the US Department for Agriculture (USDA) classification, these are weak fibers with a medium length and their uniformity is ranked as low. Micronaire values of dryland cotton fibers are on average 3.75 to 4 higher than that of pivot irrigated and lower than those of drip and row irrigated cotton (see Fig. 3.42). As the only one of all the measured micronaire values, this rate lies within the USDA premium range. Very high micronaire values are not suitable for fine yarn counts.

Cotton grown with pivot irrigation had fibers with a medium length (24.6–25.5 mm), an intermediate strength (24.4–26.5 g/tex), an intermediate uniformity (80.25–82.0%) and a short fiber index of 14.8–20.8. The micronaire was found to be between 3.4 and 3.7 with the exception of two outliers that were around 4.2.

Pivot irrigation cotton does not show any particularities concerning quality properties. All values are ranked in intermediate terms according to the USDA quality standard. With an amount of water of about 20 inches, pivot irrigated cotton had more than twice as much water at its disposition than dryland cotton.

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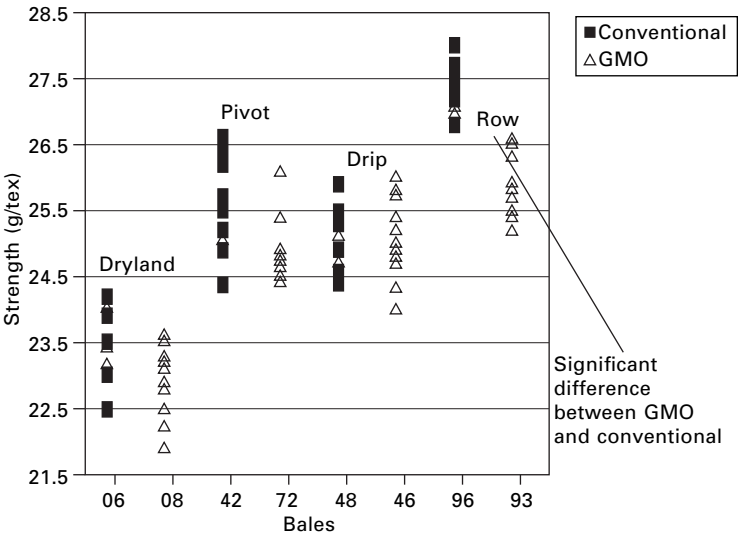


3.40 Statistical analysis of genetically modified (GMO) and non-GMO cotton in four irrigation systems (dryland, pivot, drip and row). Length is highly dependent on available water during boll development (see also Chapter 2).

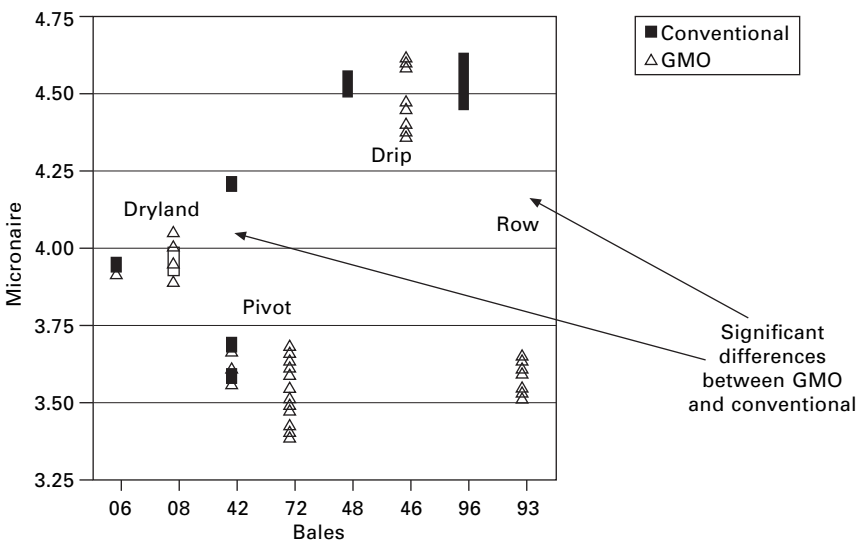
Drip irrigated cotton had fibers with a medium length of 24.75–25.5 mm, intermediate strength (24–25 g/tex) and intermediate uniformity (80.6–81.7%). Micronaire of drip irrigated cotton was within 4.3 to 4.6, which was the highest value but not within USDA's premium ranges. Drip irrigated cotton also did not show any outstanding quality properties, although it received almost 25 inches of water, which was the biggest amount of water for all assayed crops. One explanation for this fact lies in the possibly genetic limits of the variety.

Cotton grown with row irrigation presented the longest (>25.5 mm) and strongest fibers (25–28 g/tex), the highest uniformity (80.7–82.4%) and the lowest short fiber index values (11.8–19.8). The micronaire values of row irrigated cotton differed very much between the GMO and the non-GMO cotton bales. Row irrigated GMO cotton had small micronaire values between 3.5 and 3.75, but the non-GMO cotton had micronaire values between 4.4 and 4.6. The amount of water given was about 20 inches, which is comparable with the amount used for the other irrigation systems. As with row irrigation about 50% of the given water evaporates, not all the water was at the disposition of the plants (see also Section 3.12.1). Hence we consider it remarkable that row irrigated cotton presents the highest quality properties of the researched

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3.41 Statistical analysis of four irrigation systems (dryland, pivot, drip and row), all cultivated as genetically modified (GMO) and conventional varieties of cotton. Strength can depend on available water during boll development (see also Chapter 2). An interesting finding is the higher strength of the non-GMO row irrigated fibers in this study, yet the setup has to be repeated.



3.42 Statistical analysis of genetically modified (GMO) and non-GMO cotton in four irrigation systems (dryland, pivot, drip and row). Micronaire is not dependent on available water. The secondary wall development takes place after fiber length growth (see also Chapter 2). Interesting findings are the differences between GMO and non-GMO of the pivot and row irrigated setups.

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data. To explain the findings that its fiber properties were superior to those of the other cultivation systems, further quality data are needed.

The differences between GMO and non-GMO cotton in general were little – the most significant varieties could be found within row irrigation (Figs 3.41 and 3.42), but dryland cultivation showed also some differences. Comparison of GMO and non-GMO cotton irrigated with drip or pivot systems mostly shows no differences at all. (Source: Klingler and Zaech, ETH Thesis 2005)

3.12.3 Harvesting and ginning

BAT in ginning processes focuses on energy management and waste management. Recommended indicators are:

- Reduction of temperature in dry towers
- Adapted gin stand type (saw gin, roller gin)
- Adjusted number of lint cleaners for reduction of solid waste
- Solid waste with no pesticide contamination (for livestock, etc.)
- Decreased amount of fossil energy
- Alternative energy (combustion of plant material).

A study of ginning in the Texas High Plains provides indications on how to increase the quality of cotton fibers and thereby reduce additional processes for quality improvement in spinning, weaving and finishing. The quality of the cotton fiber is best on the field, the day a cotton boll opens. Weathering, harvesting, ginning and manufacturing impair the natural quality of the cotton (Antony and Mayfield 1994).

In Lubbock, Texas, where this study was carried out, all cotton is harvested with stripper harvesters. Stripping is a very efficient way of harvesting, being cheaper and quicker than spindle picking. However, it results in additional foreign matter in the cotton and causes a long chain of cleaning subsequently. Even with elaborate cleaning equipment in the gin it produces a much poorer quality of lint (Munro 1987). Klein and Schneider (1992) complain that there is no increase in quality value in the first process steps of the cotton industry – as the spinner would need it – but a reduction in value for practical application. According to the spinning industry, the quality of the raw material has decreased in recent years, although continuously better grades have been measured (Klein and Schneider 1992, Demuth 1993).

Unfortunately, this reduction in value for the spinner does not have an impact on the market price of the cotton. The specific quality parameters impacted by cleaning are not represented in the current classification system. The High Volume Instrument (HVI) is constructed to measure short fibers, neps or immature fibers. A very precise instrument able to measure these fiber properties is the AFIS (Advanced Fiber Information System), but it

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does not work as fast as the HVI and therefore cannot be used for cotton classification.

The more the first step of cleaning is done already on the field in harvesting, the better the quality. The field cleaner is installed on the harvester. It breaks up bolls and sorts burs, leafs and sticks out. All this trash is left behind on the field (Fig. 3.43).

While most of the effects of gin machinery on cotton quality are well known and described, for example in Antony and Mayfield (1994), hardly anything has been done to study the effect of a field cleaner. Bennet and Misra (1996) showed that a field cleaner (see Table 3.37) should be used as a first step of cleaning to get the least-cost cleaning configuration across the harvesting, ginning and textile mill stages. They found that field cleaning did not impact the quality parameters measured in cotton classification. (Liechtenhan 2000).

3.13 Optimizing energy supply in textile processing

Al processes in textile production require some form of energy. Electrical energy is applied for machinery in ginning, spinning, weaving, knitting, finishing and manufacturing. Some processes in finishing and air conditioning require thermal energy. Often the company does not have the choice of the prime source because the energy supply is a national task. But in earlier times textile companies settled near rivers for their private supply with hydropower. The question of BAT is not free from societal value setting, particularly in the case of nuclear power (see also Chapters 2 and 4).

3.13.1 Electrical energy

Prime sources are hydropower and nuclear power, the fossil-based resources black coal, brown coal and crude oil, as well as alternative sources such as



Field cleaner Residues

3.43 The new practice with a first cleaning step on the field leaves desired organic matter on the field, but also impacts the ginning performance.

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wind energy and photovoltaic energy. While fossil-based resources should be replaced by renewable resources one has also to consider efficiency and costs. As BAT refers to available energy the choice must be hydropower and nuclear power with some supplements of wind energy, which produces 48,000 MW globally.

3.13.2 Thermal energy

The main available prime sources are fossil: crude oil, light-fuel oil and natural gas, whereby the latter represents BAT.

3.14 Best mill practice

Before detailed definitions of BAT for the individual processing of textiles are defined, the general level of world class production is set as a standard:

- No machine part is older than 20 years.
- The average age of the equipment is under 10 years.
- Losses due to production failures are below 1%.
- All machines are running within the limits set by the machine manufacturer.
- The equipment is controlled, systematically cleaned and maintained according to the directions of the machine manufacturer.
- Experts from the machine manufacturer are periodically involved in maintenance.
- The company builds up its own capacity of personnel on machinery by instruction courses at the machine manufacturer.
- All resources and auxiliaries are evaluated periodically according to their environmental performance such as low emissions, low contaminated effluents, small amounts of waste, and harmless waste.
- Formulas and recipes are adapted to low energy and water consumption.
- All production data are recorded and documented.
- The equipment is crosslinked and electronically controlled.
- The energy consumption of the machinery is periodically recorded.
- The proceedings on the machinery are identical for all shifts.
- The environmental requirements are met constantly and the environmental safety proceedings are carried out correctly.
- The safety requirements are met constantly and the safety proceedings are carried out correctly.
- The production is inspected before delivery.
- The incoming material is inspected in the company's quality lab.
- The quality of the incoming material is defined on technical specifications.

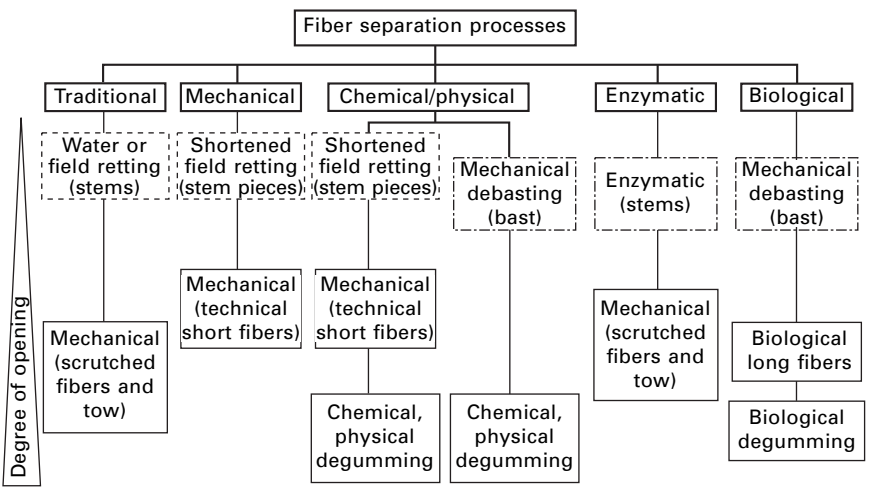
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- Secondary processes such as energy production, steam production, effluent and emission treatments are designed for flexible operation.
- Energy experts are involved in planning of energy technology.
- Experts in environmental technology are involved in planning of effluent and/or emission treatment.
- The plant capacity and its development are carefully evaluated.

Such guidelines should be part of a management system. The following sections give details for individual textile processing.

3.14.1 Hemp processing

There are several process types available for fiber opening. The procedure starts with a retting or debasting process of the harvested stems (see Fig. 3.44). Traditional retting is carried out mainly on the field and is an uncontrolled degradation process associated with a high production of organic matter. The released organic matter contributes to the organic load of surface and ground water and can present a severe environmental impact. In the alternative chemical/physical, enzymatic or biological retting, the process is carried out under controlled conditions. Chemical processing is associated



3.44 Variations in fiber preparation of hemp. The degradation processes in water or field retting contribute to an uncontrolled environmental impact as they take place on the field. Enzymatic and biological systems are controlled processes in closed conditions and with selected organisms. Chemical degumming is associated with high chemical consumption and chemically loaded effluents, whereas degradation with biological substances allows biological degradation of the effluents.

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with large amounts of contaminated effluents that cannot be considered as BAT unless the effluent is treated specifically. A biological or enzymatic retting (Leupin 2004) allows either recycling of substances or controlled degradation. The debasting is carried out mechanically in order to separate shives from fibers.

The second process is a mechanical cut of the stem material to the desired length. In the following degumming process the lignin between the fibers is removed by either chemical, enzymatic or biological treatment. Indicators for BAT are the following:

- Efficient harvest technology
- No DOC to surface and ground water
- Controlled enzymatic retting
- Mechanical debasting
- No or low chemical load in effluents
- Biodegradable load in effluents.

The traditional bast fiber harvesting procedure provides long fibers, which can be processed on available hemp spinning equipment (often wet spinning). The chemical, enzymatic processing allows open end spinning as applied with cotton. The development of an efficient harvesting technology for this process line has been neglected because of the fiber's low market share. The available technology for debasting requires a great part of manual work and cannot be considered as mature (Dreyer 2002). The fibers are trimmed for processing on cotton spinning equipment. Short fibers are applied in non-woven products.

3.14.2 Staple fiber spinning

Energy consumption is the dominant factor in spinning and BAT in spinning mills aims to reduce energy consumption. Some measures cannot be taken without consideration of products and product quality. The fineness of the yarn is directly correlated to the energy consumption by the insertion of twist per length (fineness). Other measures refer to organization and logistics of a plant to be adapted to the aimed production and by this reduce downtime.

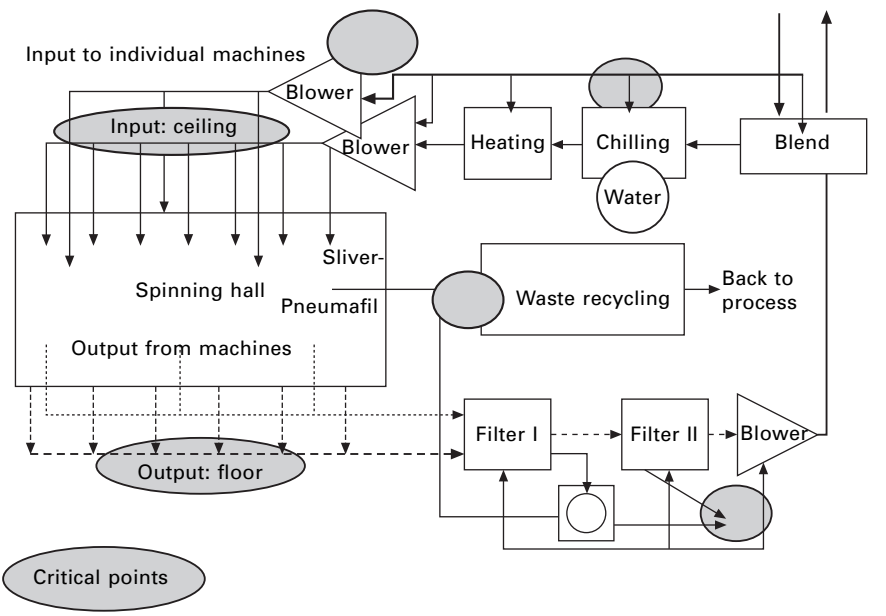
Machinery in spinning includes devices for bale opening, mixers, fine cleaner, coarse cleaner, foreign fiber detector, cards, combing equipment (preparation and combing), roving frame, ring spinning frame with spindles, rotor spinning machines, friction spinning machines and winders.

BAT for all spinning equipment with electrical energy supply aims at highest productivity and low energy consumption per hour (kWh/kg) and per tex (kWh/tex). Where productivity is interrupted, the equipment should be equipped with an automated shutdown to reduce high energy consumption in the standby state. Power units with servo or power converter can provide

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safe energy. However, available drive technology for spindles is still belt driven and not on the individual spindle. In airjet spinning compressed air is needed for the introduction of the false twist. BAT in production of compressed air includes an adaptation of the installed pressure to the required output. Suction and fan systems for prevention of fiber fly have to be adapted to efficiency and the air exchange frequency. Dimensions of fans and tubes for active fiber transport in the blowroom should be adapted to the effective production, because systems running below capacity show higher energy consumption than those that are adapted to capacity.

Optimized setup of air conditioning for the required climate (temperature and relative humidity) is a demanding task (see Fig. 3.45). Temperature can be adapted to float if the outside temperature changes rapidly. Also maintenance of the equipment contributes to BAT. To prevent losses of pressure, filters have to be cleaned periodically. The dimensions of the tubes have to be adapted to the output requirements and tested for losses. Logistics for transport of yarn packaging (combing sliver, roving and cops) should be based on well-maintained conveyor belts. BAT in illumination is achieved by appropriate lighting (in lux) compared to daylight and with efficient illuminants. Where the outside temperature differs by more than 200°C from the process temperature, insulation of the infrastructure is recommended.



3.45 BAT in air conditioning: critical points (gray areas) are input and output positions, a floating chilling (following the outside temperature), and appropriate cleaning of filters.

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3.14.3 Weaving

Besides electrical energy consumption, particularly cotton weaving mills can also perform BAT in sizing, based on thermal energy. The energy consumption of weaving machinery depends on machinery type and the associated power units. Machinery types are developed for specific product ranges, though universal operations are possible. BAT in weaving consequently focuses on energy management of machinery.

Machinery in weaving includes devices for warping, sizing, threading and all weaving machine types. High electrical energy consumption is allocated to warping and weaving. BAT for sizing equipment aims to reduce thermal energy for heating by insulation, reduction of the surface, and heat recovery from the exhaust air. BAT for sizing technology also includes a degradable sizing agent, application technology and size recovery:

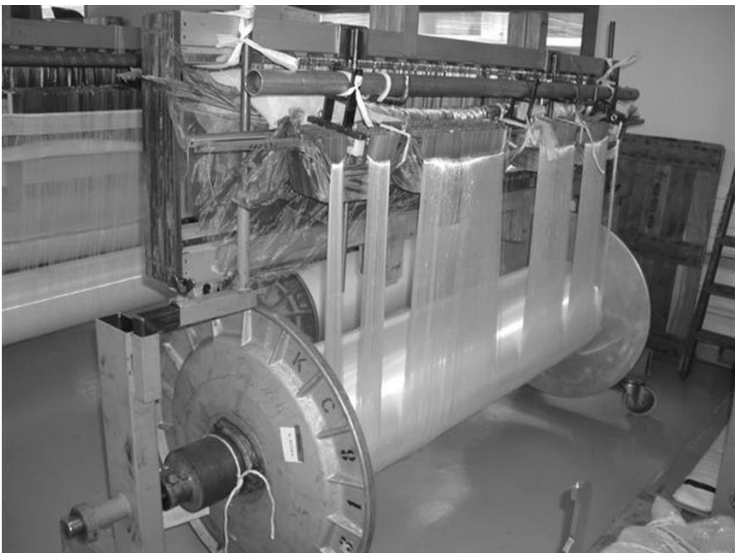
- Technology: application technology
 - Wetting
 - Steam treatment
 - Corona treatment
 - Plasma treatment
- Technology: online measurements
- Easily degradable sizing agent:
 - Biological: polysaccharides
 - Synthetic: PVA, CMC, polyacrylate
- Sizing agent recovery: ultrafiltration
- Special treatments for effluents with sizing agents.

BAT for all weaving processes could be defined as energy consumption per unit fabric weight (see also Chapter 4, Section 4.8). Threading, as weaving preparation, is carried out manually in a time-consuming process which could be automated (see Fig. 3.46).

High electrical energy consumption is allocated with warping and weaving. Wherever production is interrupted, it should be equipped with an automated shutdown to reduce high energy consumption in the standby position. Airjet machinery makes use of compressed air for the transportation of the weft yarn. BAT in production of compressed air includes an adaptation of the volume to make efficient use of the given pressure. Excess heat from the weaving equipment can be used for heating of other compartments of the infrastructure by means of heat recovery, which has to be designed for the desired capacity.

BAT for logistics of warp beam transportation are conveyor chains, if the infrastructure allows such handling. Appropriate lighting can be achieved by controlled roof windows with blind systems. In inspection the efficiency (BAT) of the illuminant and the color reproduction are to be optimized.

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3.46 Threaded warp beam. Automated threading requires a few hours while manual threading takes three to four days' labor.

3.14.4 Knitting

Knitting processes are highly productive, but require specific equipment for different knit types (see Chapter 2). Such specialization always bears the risk of deadlock time for machinery. Good planning of production can also reduce winding operations for the required number of yarn cones according to the knitting units.

Machinery in knitting includes circular, flat and fully fashioned knitting machinery. Additional conditioning of yarns for good running properties in the knitting process is preferably made in a steam unit. BAT of the steam unit is defined by the efficiency and the prime source (natural gas) for the thermal energy (see also Section 3.13 on energy supply). Wherever productivity is interrupted, that part of the plant should be equipped with an automated shutdown to reduce high energy consumption in the standby position. Suction and fan systems for prevention of fiber fly have to be adapted to maximize efficiency and optimize air exchange frequency. BAT for needle oils aims to reduce organic and metal load in the effluent load of finishing companies. BAT in illumination includes appropriate lightning, illuminant efficiency and color reproduction.

3.15 Best available technology (BAT) in finishing

Finishing processes are characterized by high energy and water consumption, high waste water load and airborne emissions (Meyer 1999b, Schellenberg

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2002). Aims for BAT are consequently to optimize energy consumption, process technology (machinery), process efficiency and formulas (chemicals). As process technology depends on product segments (Visileanu 2004a), wherein changes occur rapidly, this is a difficult task. It also depends to a certain extent on the knowledge and capability of the finisher to develop new processes on universal equipment, including updating of machinery parts. This section presents BAT in two parts: for process technology (equipment and sources) and process efficiency (formulas).

3.15.1 Finishing process technology

Machinery in finishing may include the following equipment for processing:

- Scouring vessels or machines
- Devices for mercerizing or alkaline treatment (pad or exhaust technology)
- Bleaching machines (pad or exhaust)
- Washing machines
- Drying equipment (dryer, stenter, sanforizer)
- Dyeing equipment: jet, jigger, hasp, pad systems (roll and steam)
- Printing equipment (flat, rotary, rouleaux, transfer, inkjet)
- Steamer
- Equipment for chemical finishing (pad systems, closed systems)
- Calenders (thermal and mechanical finishing)
- Logistics: layering, sewing, rotating rolls, inspection devices, packaging machines
- Quality inspection: computerized color measurement
- Supply: steam production
- Recycling: flotation, flocculation devices, filter press.

BAT for wet processing technology

Pad systems require less energy and water than exhaust technology (particularly in combination with roll systems for dyestuff development). Recommended are:

- Exhaust technology for wet-in-wet processing
- Good insulation of HT equipment (polyester)
- Closed systems in finishing application with emissions (antibacterial, flame retardancy, etc.)
- Precise dosage of ingredients (Fig. 3.47)
- Incineration of discharged air with VOC (coating and finishing).

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3.47 Automated computer-controlled dosage system for ingredients in wet processing.

BAT in laundry equipment

The main impacts are caused by energy and water consumption, whereby high process temperatures require higher energy consumption. Recommended are individual heat control of chambers and advanced water management (see below).

BAT in water management

- Reduction of rinsing and drying processes (more wet-in-wet processes)
- Reuse of baths (counter-current), heat exchange (temperatures 40–60°C)
- Heat exchange from effluents to fresh water (up to 80% feasible)
- Pumps with slower recirculation (20% slower, 50% less energy).

BAT in drying equipment

- Good insulation and reduced surface
- Automated shutdown

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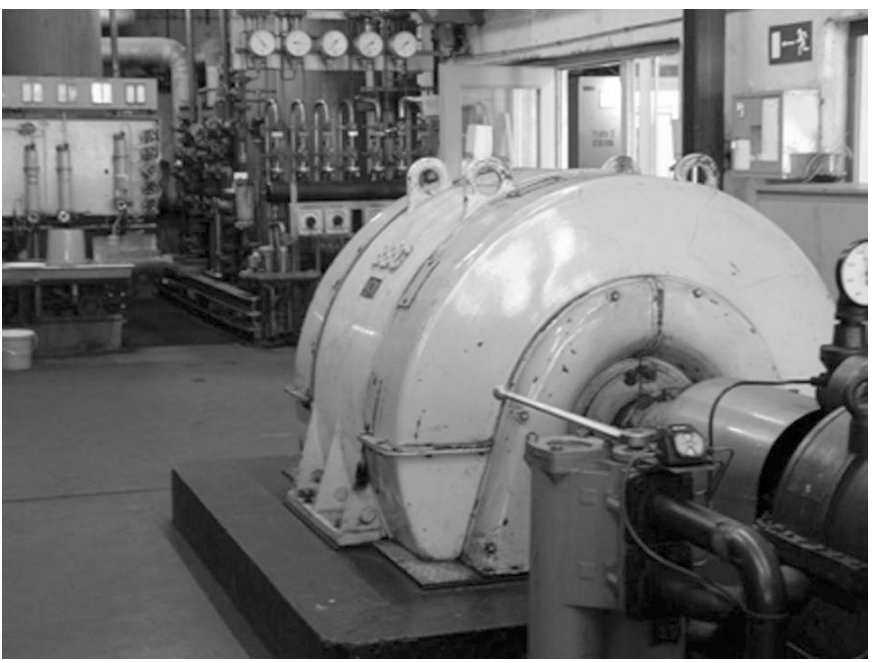
- Heat recovery of exhausted air (saves up to 50%)
- Neutralization of effluents with CO_2 emissions
- Fast motion of fabric with high temperatures for reduced heat loss.

BAT in steam production

Steam production represents a major consumer of energy in finishing processes, depending on the products of a company, namely fiber and fabric properties. Recommendations are:

- Low flow temperature
- Prime source to be natural gas for high heating value and low emissions
- Avoidance of oil and diesel (see Fig. 3.48).

Power heat coupling is not economically feasible, but might be applied in specific situations. Aspects to consider are the size of the equipment as well as the proximity to a thermal power plant.



3.48 Steam production for finishing in a diesel generator. The choice of the prime energy source determines the environmental impact, which is considerable with diesel compared to gas, but better than for crude oil.

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3.15.2 BAT of process efficiency

The aims for BAT are processes with low temperatures, short reaction time, and reduced volume of liquor ratio in batches. Along with the BREF document go some similar recommendations for reduction of water consumption, including combination of processes, but wherever chemicals may not be carried from one process to the next at least a discontinuous process or intermediate rinsing process is necessary. Quality requirements may ban such wet-in-wet processing.

Company managers are encouraged by BAT to revise their recipes for substitutes and process changes as well as to collect information from their suppliers concerning type and amount of preparation (spinning preparation, needle oils, sizing agents), residual monomers, metals, biocides and pesticides.

Summarized suggestions for process improvements combined with average values under BAT were given in Table 3.36. Suggestions for substitutions are listed in Table 3.41.

3.16 Recommendations for consumption and care

It seems only fair to add some recommendations for consumption and care. The term BAT should be replaced here by the term best practice (BP). If consumers push producers to go for BAT, they should know that they take great responsibility for environmental protection with their personal behavior in care. A comparison with industrial laundry systems may give some ideas for process innovation in developing household equipment.

3.16.1 The use phase

A number of properties determine the lifetime duration of apparel. The main requirements from the consumer's perspective are dimensional stability, pilling and color fastness. However, the information about these properties is not communicated by companies. In a reverse engineering project (Lovrenic and Tobler 1999), we analyzed the behavior of two blue T-shirts after several laundry cycles. Laundry cycles were performed according to ISO testing standards at 60°C. Dimensional stability of two knit fabrics were tested. Figure 3.49 gives the total shrinkage of the two fabric types. Fabric B shows the better performance with lower values for shrinkage, although it was labeled only for 40°C laundry. The differences in shrinkage between five and 20 laundry cycles may be caused by different finishing processes of the product lines, as found by Quaynor *et al.* (1999).

Poor color fastness represents another annoying property of apparel. Testing included the parameters clearness and purity, whereby T-shirt B

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Table 3.41 Specific recommendations for substitution for lower environmental impacts

Process	Technology	Fiber	Substances	Load	Impacts
Dyeing			Dyeing auxiliaries: dispersing agents, anti-foaming agents		Waste water load persistent
			Basic chemicals: alkali, salt, reducing and oxidizing agents		
		Wool	Residues of pesticides		
		Man-made	Spin finishes		
	Batch dyeing		Influence of dispersing and leveling agents with vat or disperse dyes	5000 mg O_2/l	
	Soaping, reductive after-treatment, softening		COD	Higher	
	Rinsing		Water consumption	2–5 × higher than dyeing	
	Continuous and semicontinuous		Water consumption	Lower than batch	
			Discharge of residual dyeing – liquors	2–200 g O_2/l	
	Padding		Liquor in padding system	10–15 l/kg to 100 l/kg	
			Residual amount	A few – 200 l	
Printing			Printing paste residues, waste water, VOC		
	Rotary printing		Printing paste residues	6.5–8.5 kg/color	
			Cleaning water	500 l	
			Ammonia, formaldehyde, methanol, alcohols, esters, aliphatic HC, acrylates, vinyl acetate, styrene, acrylonitrile		Airborne emissions
Finishing	Continuous		Residual liquor	0.5–35%	

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Table 3.41 Continued

Process	Technology	Fiber	Substances	Load	Impacts
			COD	130–200 O_2/l	Persistent, non-biodegradable, toxic
			Volatile ingredients and carryover from upstream processes		Air emissions
	Washing		Energy and water consumption		
	Dry cleaning		Organic halogenated solvents		Groundwater and soil pollution

Substance/Action	Process	Substitutes	Impacts
Surfactants: APEO	Pre-treatment	Fatty alcohols	Biodegradable
Complexing agents		Substances without P and N: polycarbonates, polyacrylates, gluconates, citrates, sugar-acrylic acid copolymers	
Antifoaming agents, mineral oils		Mineral oil free	
		Silicones	Eliminated only by abiotic processes; high concentrations hinder O_2 transfer in sludge
		Phosphoric ester (tributyl phosphate)	Strongly irritant, odor intensive
		High molecular alcohols	Odor intensive, no use in hot liquors
Sizing agents	Ultrafiltration for recycling	PVA, polyacrylates, CMC,	Reuse in integrated mills,
		Modified starch (carboxy methyl) cellulose	Recyclable
	Desizing all sustances	Oxidative (with pH > 13)	
	Combination of scouring with peroxide bleaching		Regulation of counter-current flow of alkali and peroxides

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Sodium hypochlorite	Bleaching	Hydrogen peroxide	Less whiteness
		Two step bleaching with hydrogen peroxide + sodium hypochlorate	Reduced AOX emissions
		Peroxide bleaching under strong alkaline conditions with reduction/extraction	High degree of whiteness
		Chlorine dioxide for synthetic fibers, flax and linen (hydrogen peroxide as reducing agent of sodium chlorate)	
Rinsing water from mercerization	Recycling and concentration		Reuse in process
Carriers for PET	Dyeing	High temperature conditions, polytrimethylene terephthalate (PTT)	Less harmful
Carriers based on chlorinated aromatic compounds		Benzylbenzoate or N-alkylphthalamide	Less harmful
Sodium hydrosulfite	PET after-treatment	1. short-chain sulfuric acid derivates	Biodegradable, non-corrosive, low toxicity
		2. disperse dyes, cleared in alkaline medium by hydrolytic solution (instead of reduction)	No reducing agent
Dispersing agents	Vat and sulfur dyeing	Partial substitution of vat dyes with fatty acid esters (only liquid formulation of disperse dyes)	Dyestuff palette limited, bio-eliminable + reduced amount
		Modified aromatic sulfonic acids (disperse and vat dyes) (liquid and solid formulation)	Higher bio-elimination
Dyestuff reduction with sodium sulfide	Sulfur dyeing (pre-reduced and non pre-reduced)	Glucose with dithionite, hydroxyl acetone or formamidine sulfuric acid	

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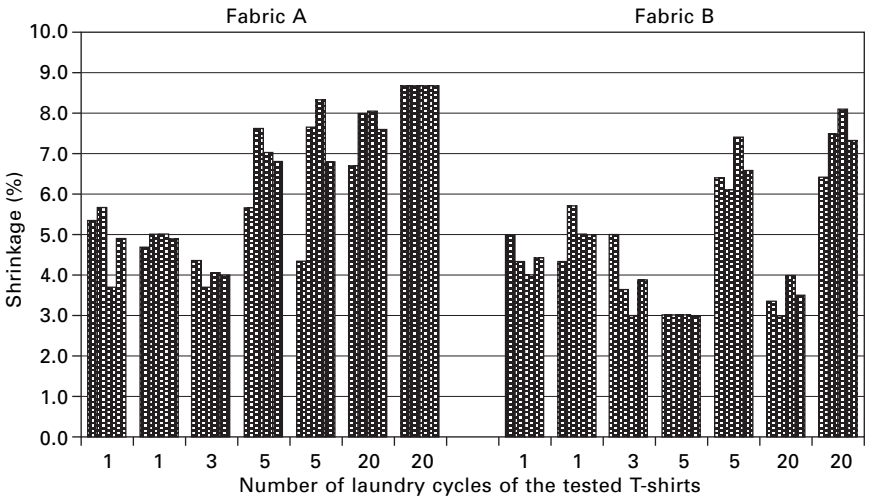
Table 3.41 Continued

Substance/action	Process	Substitutes	Impacts
Salt application for good fixation of cellulose fibers	Reactive dyeing	Bifunctional, low salt reactive dyes	>95% fixation rate
Hot water	Rinsing after dyeing	No detergents and complexing agents used	Higher energy consumption
Sodium silicate	Pad-batch dyeing of cellulose	Silicate free, highly concentrated aqueous solutions	
		Alternative process	High capital investment
Chrome dyes for high fastness	Over-dyeing	New Reactive dyestuffs	Radical changes in operations
		Low chrome, ultra-low stoichiometric chrome techniques	Lower chrome in effluents
pH controllable dyes		Isothermal dyeing conditions	Maximum of exhaustion
	Batch dyeing		Reducing bath ratios, reuse of bath
	Continuous dyeing process	Dosing padding liquor based on measurements of pick-up	Reduction of system losses
	Rapid batch dyeing	Dyestuff solution just in time, based on online measurements	
Printing	Minimizing printing supply system	Diameter of pipes	Reduction of printing paste losses
	Computer-assisted systems		Recycling of paste (not for carpets)
	Cleaning	Reuse of rinsing water pumping back paste	Reduction of water and printing paste losses
	Digital techniques	Dyestuff dosed on demand	Reduction of printing paste losses
	Inkjet printing	For short runs	Too slow
		By firing time and pumping pressure	Inspection of quantity

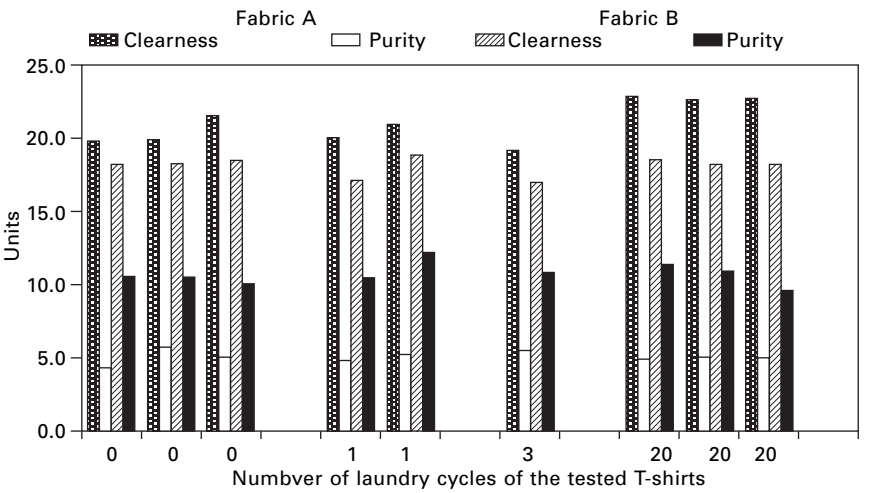
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Urea	Printing thickener	Controlled addition of moisture by foaming or spraying (not silk)	
		Reduction of urea by 50 g/kg (silk) and 80 g/kg (viscose)	
Half emulsion printing pastes (oil in water)		Little VOC, APEO free, reduced ammonia, low formaldehyde	Less aliphatic HC in air (10 g org. C/kg textile)
Finishing	Finishing	Minimum application (kiss-roll, spray, foaming)	
	Stenter frames	Reduced energy consumption/heat recovery/mechanical dewatering	
	Easy care treatment	Low formaldehyde products	
	Mothproof	Minimize and pH < 4.5/without auxiliaries	
		IR agent (carpets)	
	Softening	Spraying or foaming without cationic softener	Avoid limited dyestuff uptake
Washing	Batch washing	Drain and fill/smart rinsing	Water stream separations
	Continuous washing	Counter-current washing/heat recovery	
	Washing with halogenated VOC	Closed loop (active charcoal filter) Fenton process	
Hardly biodegradable	Waste water treatment	Low food to mass ratio	Degradable
	Advanced oxidation for pre-treatment	Fenton-like reactions	
Printing paste		Chemical oxidation	
	Mixed treatment	Adsorption to carbon followed by recycling (carbon) and incineration (sludge)	
		Biological, physical and chemical treatment, precipitation of sludge and wet oxidation, prior ozonization of recalcitrant compounds	

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3.49 Dimensional stability of two knit fabric types after one, three, five and 20 laundry cycles (with repetitions for five and 20 cycles). Fabric B shows very inconsistent quality with five and 20 cycles.



3.50 Color fastness of two knit fabrics after one, three and 20 laundry cycles.

shows better uniformity (Fig. 3.50). In the optical inspection after 20 laundry cycles, T-shirt A had faded out, which made it unlikely the consumer would wear it any more, while T-shirt B's color was still fresh compared to the new unused product. Low quality dyestuff leads to unsatisfying results.

A comparable factor for limiting a product's lifetime is pilling. The nasty neps occur when fibers are not embedded properly in the yarn structure as calculated (Cybulska 1998). In our tests the T-shirts were treated with 125,

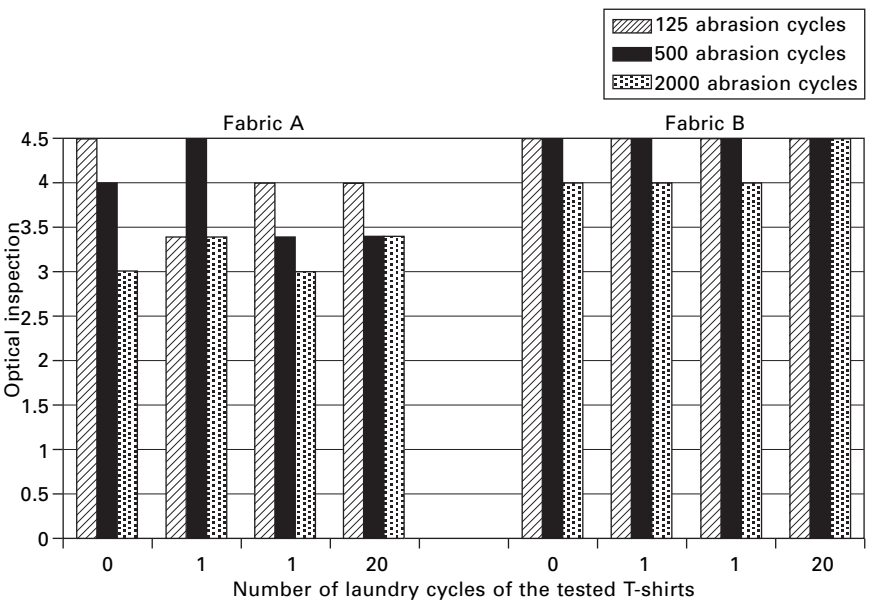
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500 and 2000 abrasion cycles before the laundry cycles. T-shirt B showed only minor changes after treatment with 2000 abrasion cycles, while changes occurred with T-shirt A even after 125 and 500 abrasion cycles (Fig. 3.51).

Consumers may prefer wrinkle-resistant apparel because they require reduced ironing. The finishing treatment with resins produces a more or less permanent wrinkle resistance through crosslinking, but often contributes to a shorter lifetime through damage of fibers.[8] Figure 3.52 gives the rating results of the two T-shirts, from which T-shirt B again shows better rating and higher uniformity.

3.16.2 Care scenarios

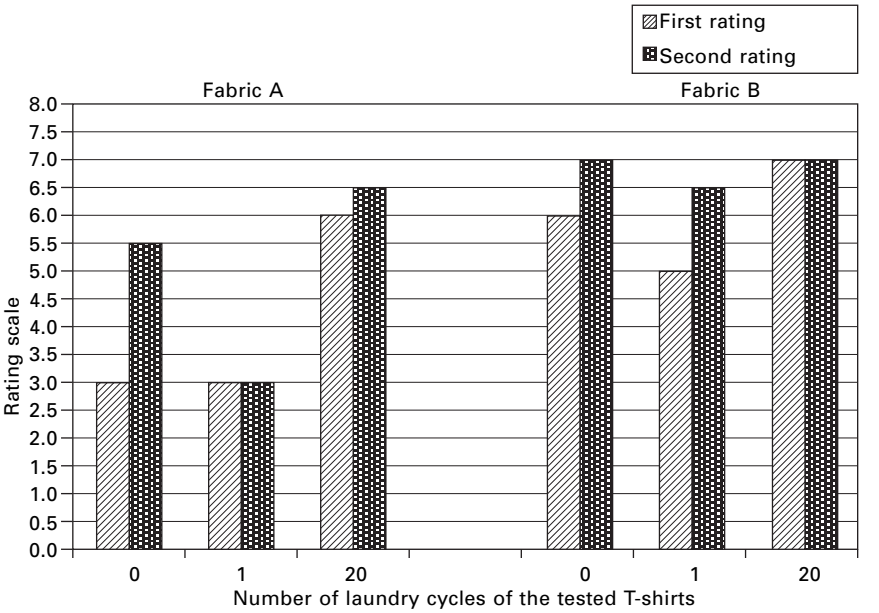
Depending on national conditions and the individual situation, laundry equipment is provided with rented property or has to be purchased. A labeling system based on energy consumption allows choosing equipment with low energy requirements. However, these labels may be valuable only for selected processes (Rohr 2003) (Fig. 3.53). Also, water management can be improved by selecting specific processes in laundering.



3.51 Pilling of two knit fabrics after one and 20 laundry cycles, equivalent to abrasion cycles.

[8]Internal statistics on the use phase at ETH.

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3.52 Wrinkle resistance of two knit fabrics after one and 20 laundry cycles.

Private domestic laundering is normally done as a continuous process in a washing machine. The fabrics remain within the same compartment (drum) while water, detergents and auxiliaries are added. The fabrics are moved around by rotating the drum. Used water is removed by spinning the drum at up to 1200 rpm and ejected.

Best practice in domestic washing machines should be defined not only by the energy label but also by the availability to adjust processes (dosage of water and laundry agent) to the actual amount of laundry to be processed.

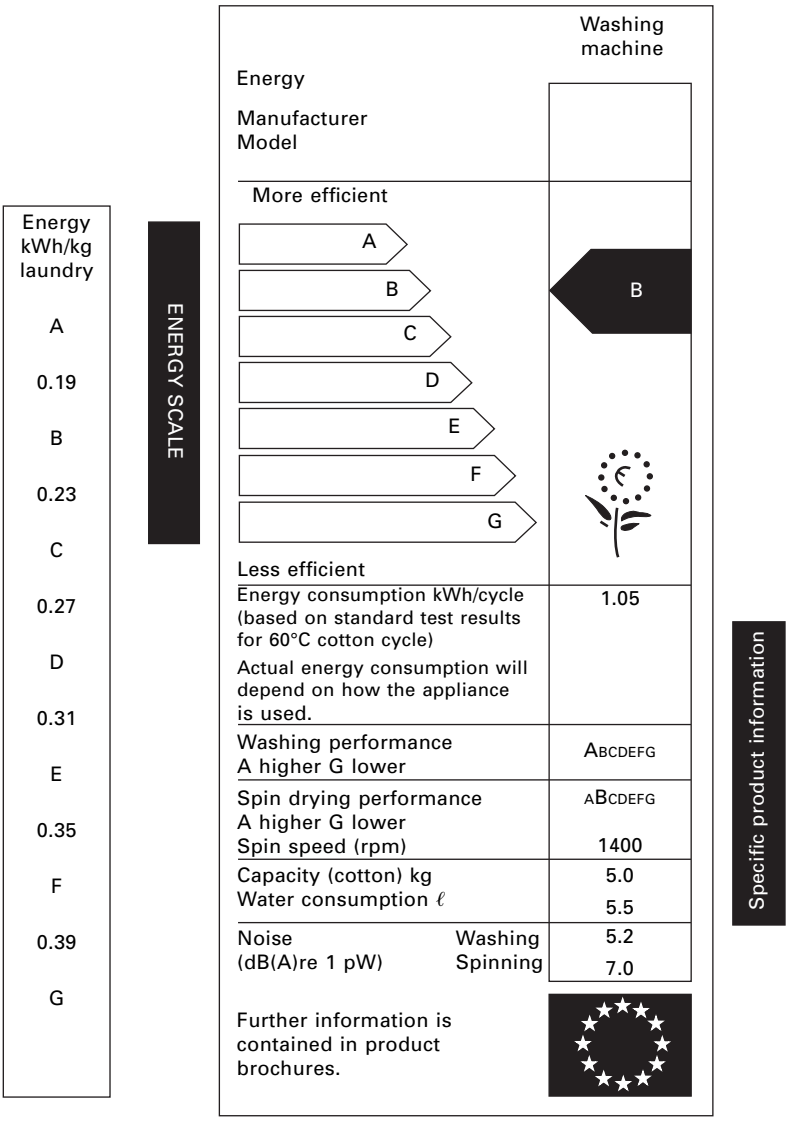
In industrial laundry equipment the fabrics are moved along individual washing compartments for each process. Between the compartments the fabrics are quenched and the remaining water can be reused (see Fig. 3.54). Industrial laundry equipment allows reuse of baths and heat recovery. However, in domestic laundry processes the deadlock time of machines is high and does not justify reuse of water or heat recovery.

Drying processes in households use a clothes line, a tumble dryer or fans. Often ironing is added for a wrinkle-free appearance. Industrial laundry works with highly efficient mangles and tunnel finishers (Fig. 3.55).

Recommendations for best practice in domestic laundry

The following recommendations help reduce the environmental impacts in care:

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3.53 Energy label for a household laundry machine.

- Choose machinery with options for different laundry quantities
- Sort laundry according to temperature, color and delicacy
- Run machines with a full load
- Choose low temperatures (in accordance with hygiene requirements)
- Apply compact laundry formulas
- Apply kit for different temperatures and fibers
- Adapt dosage to hardness grade of water

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3.54 Industrial laundry equipment with separated chambers.



3.55 Cleaned laundry after tunnel finishing (drying process).

- Apply pre-washing only for very dirty laundry
- Apply pre-treatment for specks on laundry
- Do without softener where possible

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Table 3.42 Societal trends in laundering and impacts on sustainability and quality. * 60°C required for hygiene laundry; washing machine needs operating at 100°C for hygiene warranty. **Color laundry agents do not include optical brightener

Care type	Trend	Impacts on sustainability	Impacts on quality
Frequency of washing	Increasing	Higher energy and water consumption increased effluent load	Shorter lifetime
Temperature	Lower	Lower energy consumption	Poorer hygiene*
Frequency of tumble drying	Increasing	Higher energy consumption	Shorter lifetime
Ironing	Decreasing	Lower energy consumption	None
Laundry agent formula	Compact	Lower consumption of agent, less packaging, less effluent load, less emissions (transport)	None
Laundry agent type	Color laundry agent	Less effluent load	Increased color fastness, increased graying for white laundry**

- Use a clothes line or a fan system
- Reduce ironing.

Actual trends in laundry behavior have been studied in a small trend analysis (see Table 3.42).

Hygiene requirements may interfere with BAT but are very critical today. The wide application of biocides results in ever more resistant microorganisms. Their optimized reproduction is at 35–40°C, a very popular laundry temperature. For hygiene it is recommended to apply a 60°C process for infected laundry. It is further recommended to run a 95°C process on laundry machines from time to time to prevent the diffusion of legionnaires' disease.

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4

Life cycle assessment (LCA) and ecological key figures (EKF)

Abstract: This is a complete assembly of process life cycle assessment (LCA) of textiles, complemented with a novel simplified method: the ecological key figures (EKF) for the value-added chain of textiles. LCA is based on individual measurement, including process variations from cotton growing, spinning, weaving, finishing and consumption, and is interpreted with relation to scale and scope and functionality. EKF are based on equations for individual processes along the value-added chain, taking into account main specific settings in production as well as basic environmental impact assessment.

Key words: textile life cyle assessment (LCA), ecological key figures (EKF), ecological process assessment.

This chapter addresses natural scientists and economists as well as advanced technical management and deeply interested consumers, It deals with the questions:

- How do we model systems and set boundaries?
- What assessment methods can be applied?
- How does system modeling impact the results?
- What processes cause main impacts in the value added chain?

4.1 Introduction

This chapter gives an overview on basic life cycle assessment (LCA) methodology (Section 4.2), followed by modeling criteria for textile products (Section 4.3), presented on the basis of eight case studies, covering process LCA along the value-added chain. The inventory models are given in Section 4.4 and the results in Section 4.5. The discussion (Section 4.6) includes data sensitivity for the eight case studies combined with methodological aspects. In Section 4.7 a comparison of LCA results and cost is given.

Section 4.8 presents a new, simplified method: ecological key figures (EKF), developed in theory for textile processing along the value-added chain. The method is applied in selected textile processes and the results are discussed, also under the aspect of sensitivity of the method.

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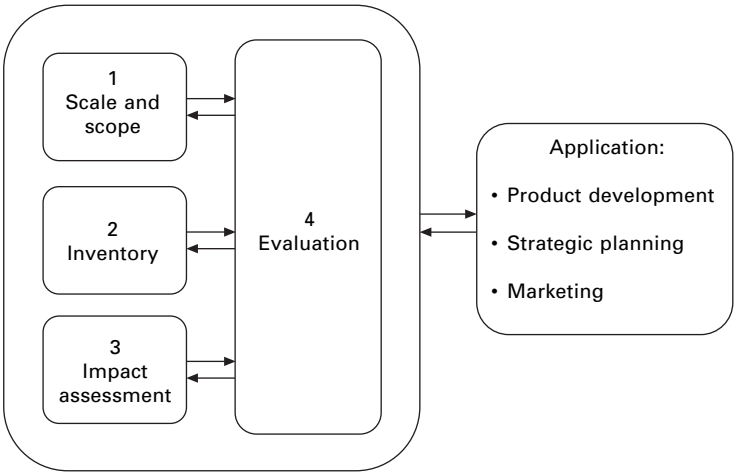
4.2 Life cycle assessment (LCA) methodology

The earliest methods for calculation of environmental impacts were developed by Müeller-Wenck (1978), followed by further developments by Habersatter (1991) for the particular case of packaging. The method defines the ecological scarcity of substances, based on economic considerations. It was refined in Buwal 250 (1996) and Braunschweig *et al*. (1998). The method 'Ökobilanzen' (BUWAL 250), based on 'Critical Volumina', forms an aggregated method by summarizing all impacts as 'Umweltbelastungspunkte' (UBP). In parallel, other methods, such as the 'Produktlinienanalyse' (product line analysis), developed (Grieshammer 1989, 1991), focusing more on life cycle of products. At this period the term 'life cycle assessment' (LCA) emerged, by defining the life cycle perspective as the integration of all processes of a product passing 'from cradle to grave'. This approach was called life cycle assessment (LCA) or life cycle analysis, as developed in the CML method at the Centrum voor Milieukunde, Leiden, by Heijungs *et al*. (1992). In order to make the methods available to practitioners, guidelines[1] were developed (SETAC 1993, Berg *et al*. 1995). A good overview of the existing methods of those days is given by Hofstetter and Brauschweig (1994). All methods are based on basic knowledge about fluxes of substances in nature (Baccini 1992) and their associated environmental impacts which have to be integrated in a database. Based on the nature of such data the models for assessment have been refined, specifying time relations of fate (Huijbregts 1999) and spatial effects (Jungbluth 2000) among others. The details of these models are not discussed in this book, but it is important to remember that the assessment models are still in a process of change.

When in the 1990s LCA methods were developed, ISO (ISO 14040, 1997; ISO 14041, 1998) set standards for the proceedings (see Fig. 4.1). Thereby four obligatory steps are indicated. In the first step, 'scale and scope', the goals of the study are indicated (See Section 4.3), together with a definition of the process area the system will include. The so-called functional unit is defined as the reference unit for all data. In the second step, inventory data, consisting of all inputs and outputs of the system processes, are collected in as much detail as possible (see Section 4.4). The third step includes the chosen scientific calculation model for impact assessment (LCIA). Here ISO 14042 (2000a) sets the following three requirements. First, impact categories (like global warming) have to be defined and equipped with appropriate indicators (CO_2, methane, etc.) and arranged in the characterization models. Second, the classification of the inventory results has to be set. Calculation of the impact indicator results follows the characterization. The third step represents the scientific assessment of the LCA, based on a chosen assessment method

[1] http://service.eea.eu.int/envirowindows/lca/kap00.htm

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4.1 Life cycle assessment according to ISO standards includes four steps: scale and scope definition, inventory (data collection), impact assessment (based on a calculation model) and evaluation of the three preceding steps. The results can be applied in the company's business processes.

(defined as LCA methodology). The fourth step in an LCA (ISO 14043, 2000b) is the evaluation, which is an interactive process to all preceding steps. Guinée *et al*. (2001) elaborated an operational guide for application of the ISO standard in LCA.

Assessment methods were first developed and consequently structured for industrial systems. According to the ISO requirements (ISO 1997, ISO 2000a, ISO 2000b) the CML method was developed basically by Heijungs *et al*. (1992). This method was followed by EcoIndicator 95 (EI 95) and EcoIndicator 99 (EI 99), whereby the latter offers options for social value setting. Both eco-indicators aggregate to points.

The implementation of LCA in companies is carried out in multiple ways, whereby LCA from the beginning is applied as a tool for decisions or development of strategies (Schaltegger and Sturm 1992). In parallel LCA was also developed for agricultural systems (Jolliet 1992). Eilrich (1991) investigated the fate of residues from the agricultural crop to the consumer. Gaillard *et al*. (1997) elaborated detailed inventories of agricultural inputs. As a consequence of the specific interrelations within ecosystems, particularly the water regime and land use, new models, such as 'Critical surface time', were proposed (Jolliet and Crettaz 1997). The agricultural aspect was further developed by Margni *et al*. (2001). The practical implementation in Swiss agriculture was shown by Rossier and Gaillard (2001).

A detailed inventory (database) of European energy systems had already been elaborated by Hofstetter and Braunschweig (1994) and Frischknecht

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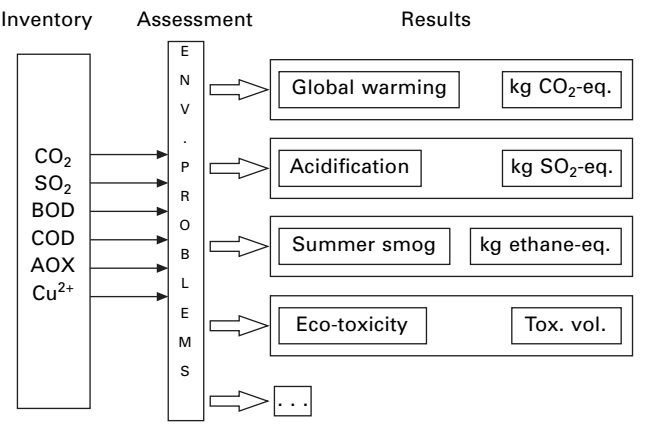
(2001). Other relevant areas of common applications, where significant inventories were collected, are disposal processes (Zimmermann *et al.* 1996), incineration processes (Hellweg 2004) and electronic waste treatment processes (Oetiker 2001), among others.

LCA methods have been introduced into various software tools such as SimaPro, Gabi and Umberto, to mention only a few cited in OeBU 2005. The structure for these tools has been influenced by the models for process modulation and material flow network (Page 2000). In 1996 a textile specific software, OeBeB Pro, was developed, but it is no longer maintained. A commercially developed system 'Blue sign', for PES textiles (Waeber 2001) is based on simplified methods, for which the algorithms are not disclosed. Also computer software for application of these methods is constantly under development in three directions: LCA methods, database and user-friendly handling.

In the following sections the methodology will be outlined and an evaluation of a practical textile application is presented.

4.2.1 CML method

The CML method (Heijungs 1992, SETAC 1996) was the first method to include the steps of classification and characterization, normalization and evaluation. In the classification step, all substances are sorted into classes according to the impact type they have on the environment (see Fig. 4.2). For each of the 12 impact categories a lead substance is selected and all



4.2 CML impact assessment method: in the inventory all substances are listed, of which transfer coefficients to water, soil and air have to be known. CML results are presented in 12 impact categories, each defined by a lead substance (right side). All substances are calculated in equivalence to the lead substance.

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other contributions are set in relation to that lead substance, according to the scientifically proved effect.

The magnitude is dealt with by applying weighting factors. This step is referred to as the characterization step. The calculated effect scores can be displayed as a graph, giving the highest calculated effect score as 100%. Thus, in classification the effects of materials can be compared within the impact category but not against other impact categories.

In the normalization step the impacts are set in relation to an average effect. The CML 92 method normalizes with effects caused by the average European during a year. In global life cycles normalization has to be adapted accordingly. Normalization enables one to see the relative contribution from the material production to each already existing effect.

In the evaluation phase the normalized effect scores are multiplied by a weighting factor representing the relative importance of the effect. The results are given as individual numbers of all impact categories. This makes it difficult for the user to decide where to take action. As the impact assessment method was developed in Europe, it is strictly limited to the European environmental situation so far. In practice we have many production steps outside Europe, so the methodology should include different reference systems.

4.2.2 EcoIndicator 95

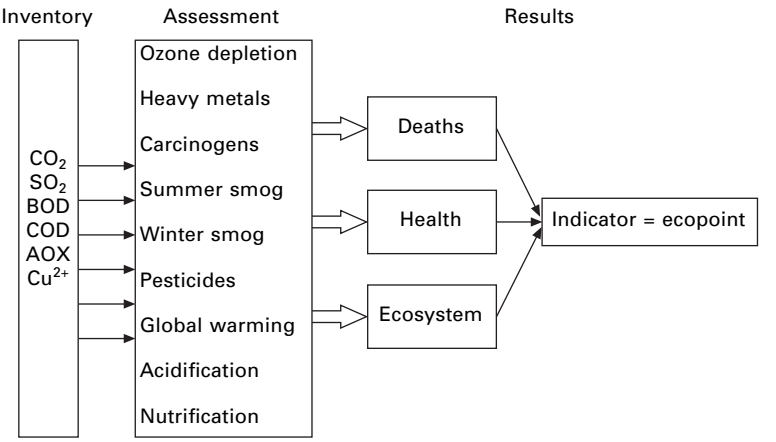
EcoIndicator 95 (Goedkoop 1995, Goedkoop and Spriensma 1996) also includes impact categories similar to the CML method, although they are reduced to nine (see Table 4.1). The calculation is similar to the CML method and includes characterization and normalization. In an additional step the contribution of all impacts to the three 'safeguard subjects' (death, health and ecosystems) is calculated (see Table 4.1 and Fig. 4.3).

Table 4.1 Impact categories, normalization factors and weighting factors of EcoIndicator 95

Impact category	Impact parameter	Normalization factor	Weighting factor
Greenhouse effect	kg CO_2-equivalent	7.65E–5	2.5
Ozone depletion	kg R11-equivalent	1.08	100
Acidification	kg SO_x -equivalent	8.88E–3	10
Eutrophication	kg PO_4-equivalent	2.62E–2	5
Heavy metals	kg Pb-equivalent	18.4	5
Carcinogenic substances	kg PAH-equivalent	92	10
Winter smog	kg SO_2-equivalent	1.06E–2	5
Summer smog	kg C_2H_4-equivalent	5.58E–2	2.5
Pesticides	kg CO_2-equivalent	1.04	25

Source: Goedkoop (1995).

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4.3 The EcoIndicator 95 method (Goedkoop, Pré-Consultants, Netherlands, 1995) includes classification, characterization, normalization and evaluation, and aggregates on safeguard subjects human health and ecosystems. Ecosystems are rated as plant biodiversity (valid only in Europe). Data for deaths are gained from epidemic studies, whereas health aspects are calculated in accordance with insurance practices (SUVA) as percentages of invalidity (100% being equivalent to one death). One death is taken as equivalent to 5% ecosystem damage.

Therefore so-called weighting factors have been defined to set the magnitude (environmental relevance) of the different impact categories. Finally, the EcoIndicator value is calculated as the sum of the weighted impact contributions (see Fig. 4.4).

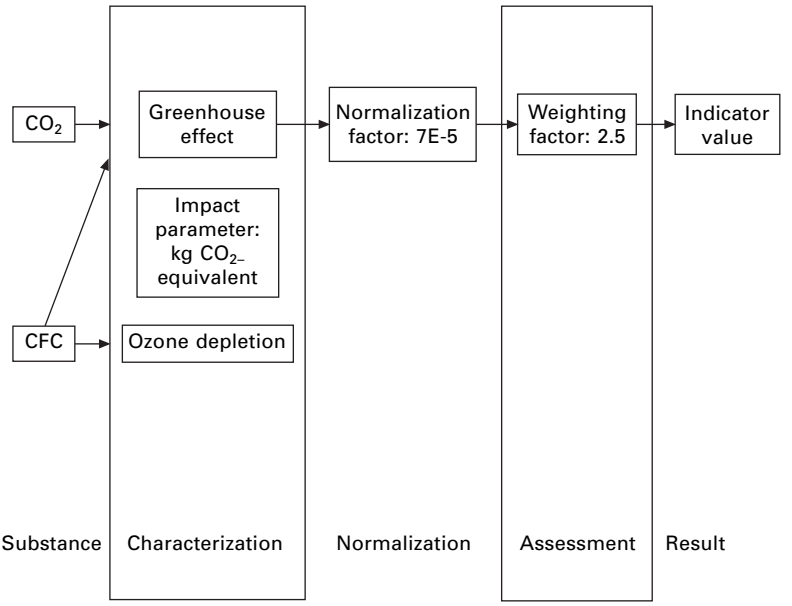
Critical points are the following. As with the CML method, the database is elaborated for the European situation. The reference for ecosystem health is based only on plant diversity of large areas and does not include animal diversity. Since birds, insects and other invertebrates are very sensitive indicators, the biodiversity of an area is not accurately defined simply by plant diversity.

4.2.3 EcoIndicator 99

EcoIndicator 99 (Goedkoop and Spriensma 1999) is the further development of the 95 model with two significant changes: new safeguard subjects and social value setting (Müller-Wenck 1996). The new safeguard subjects are human health, ecosystem quality and resources (see Table 4.2) and they are based on new impact categories such as respiratory organics, respiratory inorganics, radiation, land use, minerals and fossil fuels.

EcoIndicator 99 offers three options for social value setting by specifying

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4.4 The step-by-step procedure with EcoIndicator 95 includes the steps of characterization (equivalent to the lead substance of an impact category), normalization (the relative contribution to the effect), and assessment (weighting factor for the relevance, allowing one to aggregate the impact categories to the safeguard subjects).

Table 4.2 Impact categories and safeguard subjects of EcoIndicator 99. The numbers represent the weighting of the safeguard subjects. The impacts are calculated in units: DALY = disability adjusted life years; PAF*m^2yr = potentially affected fraction of plant species; MJ surplus = additional energy required to compensate for lower future ore grade

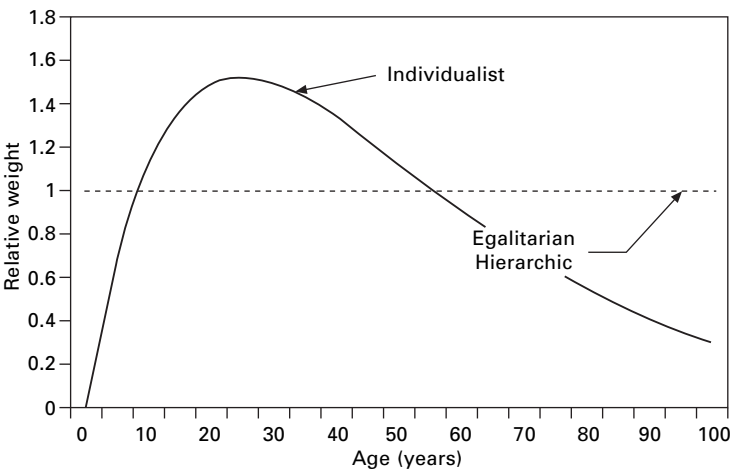
Impact category	Unit	Factor
Human health (400)		
Carcinogens	DALY	1
Respiratory organics	DALY	1
Respiratory inorganics	DALY	1
Climate change	DALY	1
Radiation	DALY	1
Ozone layer	DALY	1
Ecosystem quality (400)		
Ecotoxicity	PAF*m^2yr	0.1
Acidification/eutrophication	PDF*m^2yr	1
Land use	PDF*m^2yr	1
Resources (200)		
Minerals	MJ surplus	1
Fossil fuels	MJ surplus	1

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three fundamental value settings in society (see Fig. 4.5) (Hofstetter 1998):

- **E: the egalitarian**. The egalitarian takes a long-term perspective, valuing tomorrow's generation as high as today's generation, and people living at far distances as important as his own family. Minimal scientific indications are sufficient for an impact assessment in LCA. (Cautious values)
- **I: the individualist**. The individualist takes a short-term perspective, ranking today's generation higher than the next generation. He only accepts stringent, scientifically proven relations between hazardous substances and environmental impacts in LCA. (Risk acceptance)
- **H: the hierarchic**. The hierarchic evaluates carefully between present and future impacts. As soon as relations between hazardous substances and environmental impacts are scientifically discussed, but even not yet proven, he accepts them as being the subject of LCA.

Critical remarks are the following. There is only one really new impact category including a new indicator to the LCA, namely land use. All other impact categories are a new arrangement of known indicators. Water, a very elementary indicator, is not rated as 'resources'. The three options for societal values open a field of differentiation from the viewpoint of social sciences, but for the practitioners it becomes difficult to make the right choice.



4.5 The social perspective with EI 99 (cultural theory) includes a value setting in terms of weighting of time when the impact will become effective. The orientation of the individualist value is focused on short-term impacts. Hierarchics and egalitarians also consider long-term impacts. The hierarchic relies on regulations while the egalitarian considers more natural regulation.

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Moreover, LCA could be manipulated by selecting the method which proves the lowest impacts (see Section 4.6.2 on sensitivity analysis).

4.2.4 Further development of methods

In the recently developed CML baseline 2000 methods water is finally included as a resource as well as a large variety of pesticides. This makes the new method very sensitive in agricultural areas, a reason to apply it for our LCA of cotton growing. Scientific research on 'impact 2002' currently deals with models for short-term and long-term impacts (Jolliet 2003) which eventually will lead to the most appropriate method. Research and industry have learned how results can change by applying different methods. For comparative LCA it seems to be reasonable to stay with an established method, even if the database is poor and impact indicator modeling does not meet the state-of-the-art in science, otherwise earlier results have to be recalculated. On the other hand, significant improvements have been achieved with the new methods considering modeling of the environment.

4.3 Eight case studies: scale and scope

The value-added chain of textiles, representing the life cycle of apparel, includes a great number of businesses with different process technology (see Chapter 3), operating with different production units. Consequently, there is no functional unit that could be applied from agriculture of cotton up to the use and disposal of apparel. Reference fluxes for life cycle assessment (LCA) have to be defined according to technical conditions. Besides LCA, applied in product development, also quality and costs of products with a comparable function for the consumer have to be taken into consideration. Only modeling of technical specifications and product quality, as addressed in Chapter 2, can provide useful scenarios for life cycle inventories. Companies are not satisfied with LCA data based on average production, because they have to show the significance of their environmental impacts for ISO 14001.

This section will indicate how a system is defined by means of modeling of processes, how functional units are chosen for textile products and how inventory data are collected, including calculations of the chosen functional unit. Modeling of textile life cycles sets reference fluxes from raw material up to the use and disposal, based on modern process technology, comparable values for consumer use and feasible costs in production. Since energy use and water consumption represent the first priority, different process technologies in cotton production, spinning and weaving are elaborated and their environmental impacts are compared.

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4.3.1 System modeling of the case studies

System borders have to be set appropriate to the scale and scope of the study by including all relevant environmental impacts. For industry often only a selected stage in the life cycle is of interest, for instance to decide what technology should be applied in spinning or finishing. In such a case many inputs are negligible, if they are equally part of both technologies.

Consumers might be interested in a whole life cycle of an individual product they intend to buy, or what fibers they should prefer for ecological reasons. The first question is very time consuming to answer and is highly dependent on the process technology applied, while the second question cannot be answered independently of the use purpose of a textile product. Consequently for every modeling the questions of relevance have to be evaluated very carefully. On the other hand, system modeling cannot be performed independently of the availability of data, as will be shown in the individual cases of textile LCA.

The next section will provide information about individual stages in the life cycle of textiles and is based on the studies shown in Table 4.3.

Cotton growing

Our LCA study A was carried out in the Texas High Plains (USA). The High Plains lie on a plateau with an elevation of about 915 m. This is a major US cotton production area of 1.4–1.6 million hectares, representing over 60% of the state's acreage. The main varieties grown are mid-staple stripper varieties HS 200 and HS 26 with a 10-year average yield of 485 lb/acre.

Table 4.3 The eight case studies

A: LCA of cotton growing scenarios (Schaerer 2001, Tobler and Schaerer 2002, 2003)
B: Process LCA of different cotton fabrics (spinning and weaving: new technology) (Kaspar and Kaspar 2000, Tobler *et al*. 2002)
C: Process LCA of mixed fabrics (spinning and weaving: advanced technology) (Luchsinger 2002, Tobler *et al*. 2002)
D: Process LCA of two comparable cotton products in two finishing companies (Stokar 1996, Zwicker 1997, Tobler 2000b)
E: Process LCA in finishing of two different products within the same company (Bernasconi and Ackermann 2005, Tobler *et al*. 2005)
F: Process LCA in professional and private laundry (Zbinden 2005, Tobler *et al*. 2005)
G: Comparison of production, reuse and recycling of a polyester product (Mathieu 2003, Tobler and Mathieu 2003)
H: Substance fluxes and LCA of PA 6 (Jaun 2005, Tobler and Jaun 2005)

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The growing season is rather short with a planting time from mid-April to June and a harvesting time from September until December. Poor annual rainfall with an average of 16–25 cm determines a semi-desert climate with variations in the north–south and east–west directions (Ethridge 1977). Due to the dry climate (semi-desert) cotton in this area is mainly irrigated, and the water is taken from the Ogallala aquifer, a large underground lake. Dangerously, the level of this aquifer is being lowered year by year, because consumption exceeds refill by rainfall and surface water (Spaar 1997). Winds, droughts and hail contribute to soil erosion. Soils consist of little organic matter and show a lack of potassium if used for cotton growing. The use of heavy machinery contributes to soil compaction. However, the long-term impacts are merely received as cost drivers by regional researchers (Terrell and Johnson 1999). Due to the altitude, pressure from pests is not enormous, but the boll weevil periodically reduces yields (see also Chapters 2 and 3).

We chose the Texas High Plains as a case study because of the support of Texas Tech in Lubbock, the International Textile Center (ITC) in Lubbock and of many farmers in the region and because of the availability of regional statistics. In our study the same variety was investigated with variations in irrigation systems and growing regimes (conventional, organic and GMO) of two farmers in the same region. Two actual irrigation scenarios are chosen: the water-saving LEPA (Low Energy Precision Application) system and the older furrow irrigation.

Earlier practices like spray irrigation with high-power spray units or spraying by aircraft have been replaced by more efficient irrigation systems. The LEPA consists of small water sprayers, hanging down from a water-carrying pipe. At the bottom of each pipe, situated very close to the ground, is a nozzle that sprays water onto the crops. With this equipment less water is lost to evaporation and wind drift than with a traditional spray-irrigation system. Besides electricity savings, these systems allow more than 90% of the water to be used by the crop (USGS 2001).

Probably one of the oldest methods of irrigating fields is furrow irrigation, a type of flood irrigation. Farmers flow water down small trenches running through their crops made by tillage implements. It is a cheap and low-tech but not very efficient method. Although less water is lost to evaporation than in spray irrigation, more water can be lost from runoff at the edges of the fields (USGS 2001). Drip irrigation is based on a water tube system on or beneath the soil surface. Unfortunately no drip irrigation scenario was applied on our test area. The dryland (rain-grown) growing regime, also selected as a scenario, is called ‘environmentally friendly’ because it does not make use of any irrigation. Generally rainfall with an average of 18 inches is considered adequate for crop production. The high variability within years makes non-irrigated crop production much more risky than irrigated production. This

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risk has even increased by the drought of the last few years. At least 'organic cotton', another environmentally friendly scenario, is grown without any pesticides (see Chapter 2) and with an efficient irrigation system.

The season of 2001 was taken as inventory for cotton. All inputs and outputs of agrochemicals (including their life cycles) as well as all mechanical operations for applications are included. Production of machinery for tillage and for the irrigation systems is not included because this may be different from farmer to farmer. An overview of the five scenarios is given later in Table 4.4 (Section 4.3.2). On farm B, 'BDryland', 'BFurrow' and 'BLEPA' cotton was cultivated, while 'WOrganic' and 'WRR' (GMO: Roundup Ready) are LEPA systems that were both cultivated on farm W.

Since both farmers grew the same variety, HS 26, no differences should occur due to specific requirements for individual varieties. The allocation of the impacts achieved by the product (cotton fibers) and its by-product (seeds) is based on economic values.

Industrial systems

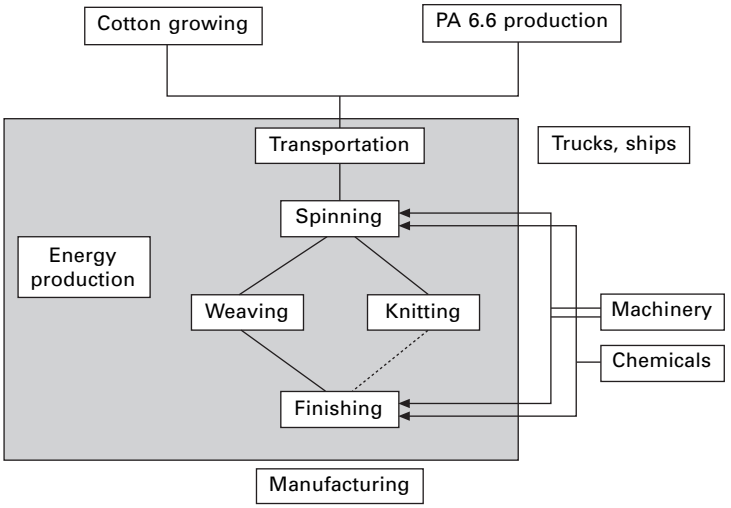
The value-added chain of textiles, representing the life cycle of apparel, often includes a considerable number of companies, each of them applying a variety of process technology. Many European companies and consumers care not only for quality and costs of products but also for environmental impacts associated with textile processing. Although quality of the individual process technology is well known, communication, based on technical specification along the value-added chain, is rather poor. Process-based LCA provides information on environmental impacts as well as data for product development.

The product-related LCA studies in spinning and weaving are based on different models. In study B only production processes were evaluated, while study C also included maintenance and administration of the company. The purpose of study B was to evaluate environmental impacts and economics (see Section 4.7 on LCA costs) of selected products. In Fig. 4.6 the modeling of the production process system is presented.

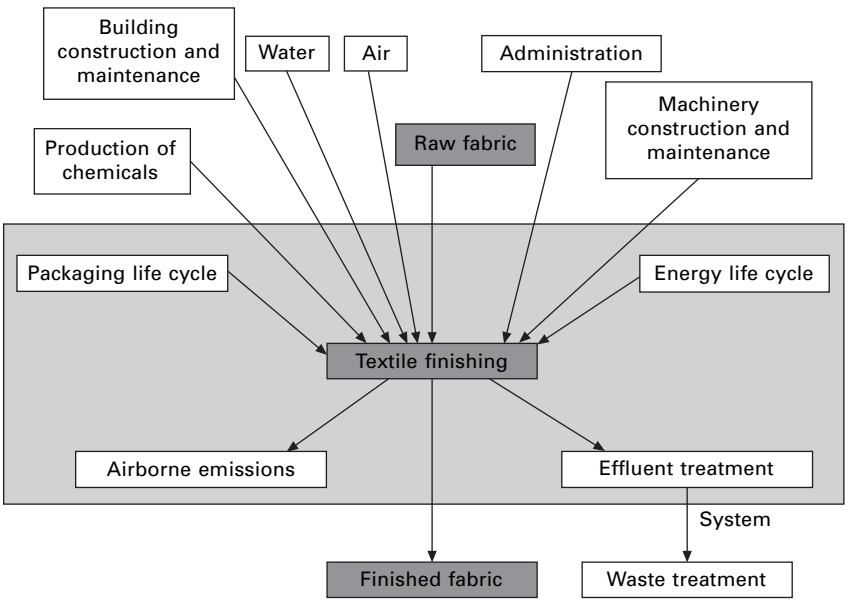
Modeling in case study C includes also growing of cotton, spinning, weaving, finishing and transportation of fabrics. Since energy use is of great importance, process technologies in yarn production and fabric production are considered as well as different transportation, regarding their cost and environmental impacts. For the company-based model (study C in Fig. 4.7) also energy generation and the average transportation of raw material are included (see also Figs 4.16 and 4.17 and Table 4.11 in Section 4.4).

The product specific studies D and E were carried out in different finishing companies. The aim of study D was to compare two companies with comparable systems (Fig. 4.8). The system border was structured as follows.

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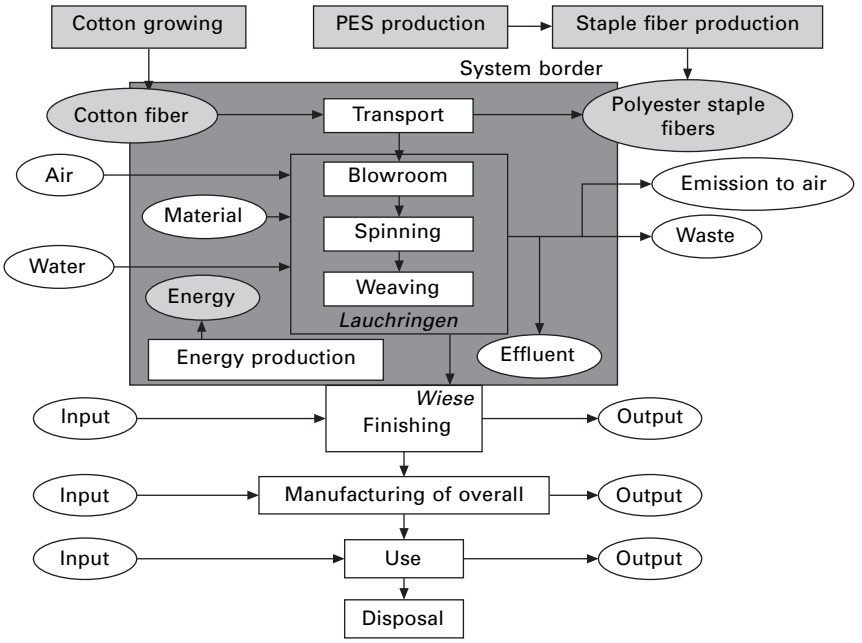
4.6 System modeling of case study B. The gray frame shows the processes included in the LCA.



4.7 System modeling of case study C. Dark gray shows the main system (plant at Lauchringen); light gray shows additions for the enlarged system with cotton growing and PES production (plant at Wiese).

The main system in both companies includes all processes and outputs such as emissions and effluents. Hereby, transfer coefficients of substances were set according to the physical and chemical properties of the substances, as

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4.8 System modeling of case study D. The main system is underlain in dark gray, the additional flotation and the additional energy supply in light gray.

well as the technology applied. Additionally, energy supply (the impacts on the life cycle of the prime source) was included for both systems A and B. For system B, an option including flotation processes, carried out at the company, was calculated.

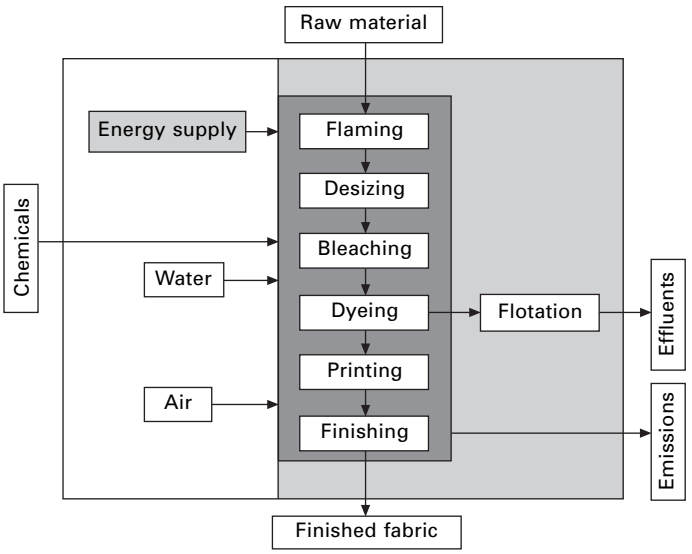
Study E investigates two fabrics produced by different technologies within the same company (Fig. 4.9). Finishing companies show a high variation in process technology as well as energy supply and heat recovery. Accordingly, comparison includes also differences in process technology.

Study F was carried out in a professional laundry, whereby a specific system model was developed, according also to the availability of inventory data (see Fig. 4.10).

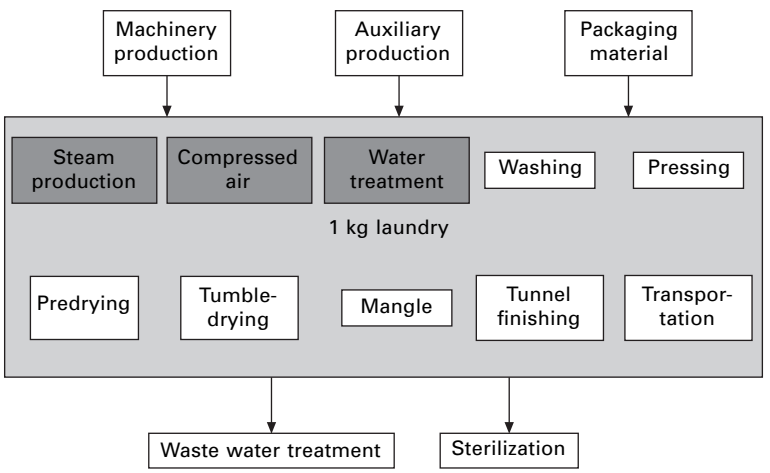
LCA data based on company data

All the systems modeled above only include production processes (except for study C). But companies also carry out maintenance and all products require their share of administration, referred to as business processes (see Chapter 5). While individual consumption of substances, water, energy and so on of individual products can be measured, data on maintenance, heat

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4.9 System modeling of the processes in case study E. The dark gray system includes all finishing processes and supply processes (energy life cycle, effluent treatment, airborne emissions and packaging life cycle) involved in the processing of the raw fabric to a finished fabric. Processes outside the system are not included.



4.10 System modelling of case study F. Dark gray shows the investigated system with included processes and supply processes (light gray) referring to 1 kg of laundry as the functional unit. Machinery and auxiliary production, packaging material and waste water treatment and sterilization are excluded, as they are carried out outside the plant and therefore cannot be influenced by the company.

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recovery, airborne emissions, etc., are mainly available as annual production. In such cases it seems feasible to relate annual production to the considered functional unit, although this includes of course inaccuracy because output differs with product quality. Dahllöff (2003b) states the same problems with the textile production study.

Investigating an individual product along the value-added chain often includes processes in a number of different companies. In order to keep the effort in data collection low the model can be based on average company data. Such data refer to the company's general efficiency and may vary from the effective environmental impact due to individual processing and/or technology. The range of this difference can be estimated from study E, where two products within the same company were investigated. The 'company model' was chosen for study G, where comparison between production, reuse and downcycling of a polyester T-shirt was studied. Also case study H depends on the company model with additions of import–export data from the Swiss Customs office.

4.3.2 The products and their functional units

The cotton fiber

LCA in agriculture are carried out with the scope of production (for the farmer) and a functional unit 'land use' (acres or ha) or with the scope of the product (for the consumer) and the functional unit kg (Koellner 2001).

Evidently the relation between the two units is determined by the yield. If production is chosen as scope, the system must include at least one year of the production system in order to include all relevant impacts (Nemecek *et al*. 2005). Where crop rotation is applied, the system preferably includes one rotation period for the allocation of all impacts.

In our case study no crop rotation was carried out for climatic and economic reasons. The short period for growth does not allow an alternative winter crop, and rotation with other crops during the summer growth period is not considered economic by the farmers. The cotton-growing scenarios are represented in Table 4.4. They were chosen to show specific differences in relation to the irrigation scenarios and with regard to organic, conventional and genetically modified cotton growing. Two farmers were involved in the five scenarios and their individual practices turned out to be highly significant.

Textile fabrics

For case study B we selected two products, whereby not the entire value-added chain was considered (see Fig. 4.3). This decision was taken in order

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Table 4.4 Definition of the five cotton-growing scenarios investigated in case study A based on indicators. The corresponding inventory includes all inputs and outputs together with the applications

	BDryland	BFurrow	BLEPA	WOrganic	WRR
Acreage	58.26 ha	8.33 ha	77.68 ha	24.78 ha	24.78 ha
Irrigation	None	Furrow	LEPA	LEPA	LEPA
Water use	None	3.5 million l/ha	2.3 million l/ha	1.3 million l/ha	1.3 million l/ha
Variety	Paymaster HS26	Paymaster HS26	Paymaster HS26	Paymaster HS26	Paymaster 2326RR
Fungicides	Captan	Captan	Captan	None	Many
Herbicides	Trifluralin, caparol	Trifluralin, caparol	Trifluralin, caparol	None	Trifluralin, caparol, Roundup Ultra
Insecticides	Malathion	Thimet, malathion	Thimet, malathion	None	Temik, orthene
Growth regulators	None	None	None	None	Pix
Defoliants	Cyclone	Cyclone	Cyclone	None	Cyclone
Fertilizers	None	None	Nitrogen		Manure

to present coherent data for textile specifications (TS), environmental impacts (LCA) and costs (see Section 4.7). The selected products were jeans and T-shirts (ladies' outerwear), most of them made of cotton and an alternative made of synthetic fibers. This decision was also based on the trends of the market where cotton is (still) the most prominent raw material, followed by man-made fibers.[2] For classical application of the selected apparel, cotton is by far the most important fiber. Criteria for this choice are the natural fiber, a nice hand, and comfort in wear as well as good properties for washing. Although the trend towards elastic apparel is growing, pure cotton products were selected. Regarding consumer preferences, a tendency for specific fashion apparel like shirts made of synthetic fibers could be observed,[3] particularly with young people. This trend might be based on the influence of sportswear. Besides fashion, properties like fast drying, lack of wrinkles and non-ironing were considered to be criteria for this market. The fabrics chosen for study B were T-shirts (cotton and nylon) of 150 g/m^2 and jeans (ring-spun and OE-spun) of 231 g/m^2 (see Table 4.5). The scope of comparing two T-shirt types (cotton or nylon) is not based on equal quality (regarding chemical and physical properties) but simply on the consumer's choice of fashion (see also Section 5.5 in Chapter 5).

The inventory included energy of the individual transportation of the raw material as well as process technology (spinning, knitting, weaving) for the fabric. Modern spinning technology (Rieter) and airjet weaving technology (Sulzer L5200) were applied. The functional unit in yarn production is length (in m) of a specific fineness (tex = g/km yarn). Yarn may not be calculated by weight because energy of production depends strongly on its fineness. In weaving the functional unit was calculated as the sum of the weight of warp and weft yarns per m^2, based on their individual fineness. Small amounts of auxiliaries like wax, sizing and lubricants for machinery were not included.

Table 4.5 Definition of the products and variations investigated in case study B: jeans for leisure and T-shirts for fashion. OE = rotor spun, DTY = drawn texturized yarn

Product	Spinning	Fineness (tex)	Fabric	Weight
Jeans	Ring, combed	50/74	W 24/f 15	231 g/m^2
Jeans	Ring, combed	50/74	W 15/f 24	231 g/m^2
Jeans	OE, carded	50/74	W 24/f 15	231 g/m^2
T-shirts	Ring, combed	20	Single jersey	150 g/m^2
Nylons	DTY	2.3	Single jersey	30 g/m^2
Nylon shirts	DTY	20	Single jersey	150 g/m^2

[2]www.cottoninc.com
[3]www.cirfs.org

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In case study C an overall fabric with a fabric weight of 0.2l kg/m^2 was investigated. The calculation of the input material in weaving was based on the weight per m^2 (functional unit). The warp consisted of 31.71 tex ring yarn and the weft of 35.71 tex OE yarn. The supply of the defined yarn qualities was calculated in Table 4.6. An advanced technology (M8300 multiphase weaving machinery by Sulzer) was applied for weaving.

In study D two fabrics were analyzed and compared considering different finishing processes and technology (see Table 4.7). The woven fabric of company A was a pure cellulosic fabric made of 57% cotton and 43% viscose. It was produced on two lines with different processing: exhaust

Table 4.6 Calculation for the functional unit of a fabric (selection of the inventory)

Fabric parameter	Density (count/cm)	Fineness (tex)	Fineness (Nm)	Yarn type
Warp	32	31.25	32	Ring spun
Weft	24	35.71	28	OE spun
Weight of 1 m^2	Yarn length (m/FE)	Weight blend (kg/FE)	Weight CO (35%) (kg/FE)	Weight PES (65%) (kg/FE)
Warp	3200	0.100	0.035	0.065
Weft	2400	0.086	0.030	0.056
Total	5600	0.186	0.065	0.120

Table 4.7 Definition of the production processes of the evaluated product lines. The two fabrics are woven (A), being a blend of cotton/viscose (57%/43%) with 118 g/m^2, and knitwear (B), cotton with some lycra (96%/4%), somewhat heavier, with 148 g/m^2. However, the processes carried out were similarly designed for both fabrics, even if the woven fabric has to be desized and is not mercerized. In company A the different dyeing technologies of pad (by foulard) and exhaust (by jet) were applied. In company B, two different dyestuffs and one printing process were applied

Material from company A		Material from Company B		
Woven: cotton 57%, viscose 43%		Knitware: cotton 96%, lycra 4%		
A1	A2	B1	B2	B3
Scouring	Scouring	Scouring	Scouring	Scouring
Desizing	Desizing			
Bleaching (jet)	Bleaching (jet)	Bleaching (pad system)	Bleaching (pad system)	Bleaching (pad system)
		Mercerizing	Mercerizing	Mercerizing
Dyeing (jet)	Dyeing (pad system)	Dyeing 'Begonie' (pad system)	Dyeing 'Campari' (pad system)	Printing
Finishing	Finishing	Finishing	Finishing	Finishing

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technology with jet machinery and pad steam on a foulard. The fabric of company B is an elastic knitwear made of 96% cotton and 4% lycra. For superior quality the fabrics were mercerized after bleaching. As a functional unit 200 m of each fabric (final length) were taken. Three lines were studied with differences in dyeing and printing technology.

Another LCA (case study E) in finishing was carried out in a third company, where two woven fabrics were analyzed: an overall fabric for medical clothes (M) and a Manchester fabric for leisure trousers (L). The product specifications are given in Table 4.8. The comparison was based on both an average production size (length) which was typical for the fabric types as well as on the functional unit of 1 meter length.

The laundry study (F) included professional laundering, mainly from hospitals, and an average European household laundry. Particularly, the different drying processes were analyzed and compared. As a functional unit 1 kg of laundry was chosen.

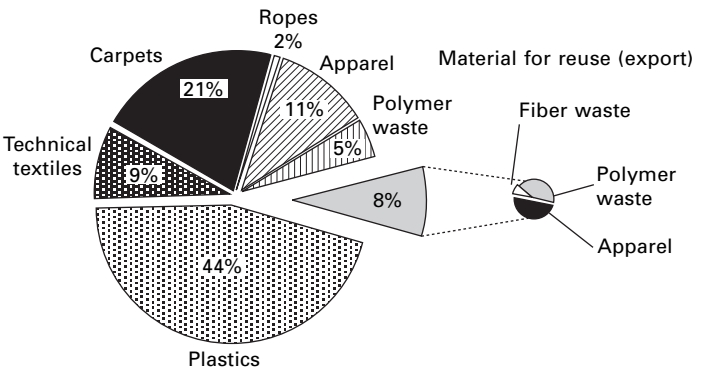
Study G aimed to compare the production of a specific pure PES T-shirt 'Mikeli' with the options reuse by means of injection molding or recycling of the fabric shredders. The functional unit was '1 T-shirt'.

Study H analyzed material flows of polyamide PA 6 and PA 6.6 from and to Switzerland. Figure 4.11 gives the product groups of an annual production in Switzerland. A small fraction, the rope for sports made of PA 6, was chosen for the development of recycling options for remanufacturing to plastic parts, combined with an 'LCA light', providing preliminarily results, based on the calculated model with literature data. The functional unit was chosen to be 1 kg material for the production of plastic parts.

Table 4.8 Definition of the two fabrics and the processes of case study E

Specification	Product: M	Product: L
Article	68694	42040
Fibers	80% cotton 18% acrylic 2% elastane	65% PES 35% cotton
Warp	32 counts/cm	36 counts/cm
Weft	66 counts/cm	24.5 counts/cm
Weight	500 g/m (finished)	344 g/m (finished)
Width	150 cm (finished)	160 cm (finished)
Average length	2012.8 m (gray) 1672.3 m (finished)	4206.0 m (gray) 4028.2 m (finished)
Weave	Cord	K2/1S
Finish	Soft, D37	Standard EII
Dyeing	Brasil (brown)	Bugatti Royal (blue)
Others	26 ribs/10 cm Quality standard LQS 103 Eko-Tex Standard 100	No azo dyestuffs Quality standard LQS 201 Eko-Tex Standard 100

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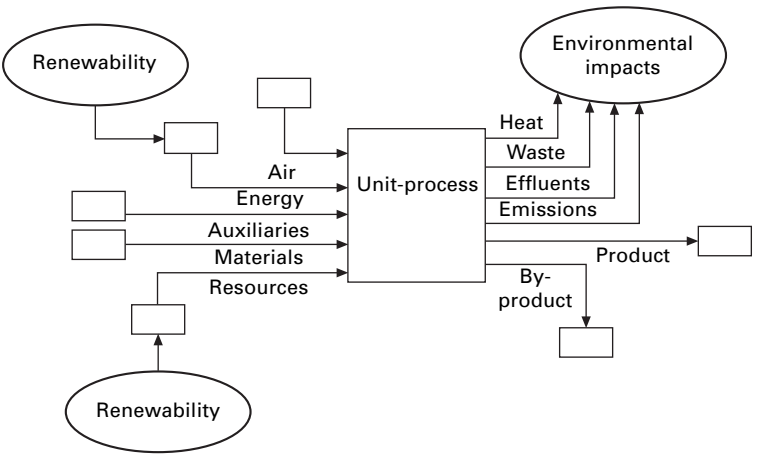
4.11 Case study H: reuse of Swiss nylon (total ~34,000 tons/year) for thermal incineration in incineration plants (KVA) and exported material for reuse.

4.4 Life cycle inventory (LCI)

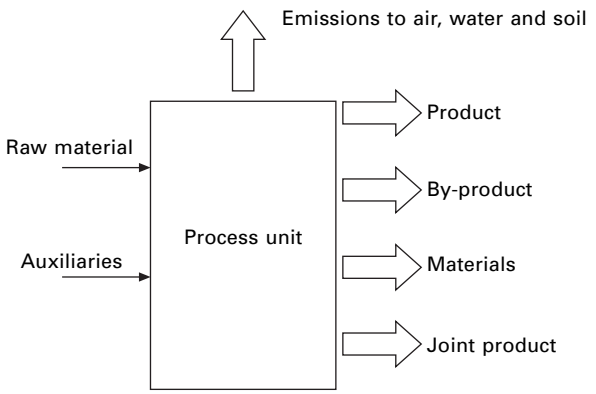
The life cycle inventory (LCI) is based on a series of unit processes, each of them consisting of all inputs and outputs which are necessary and occur (see Fig. 4.12). The inputs are all resources (land use), energy and materials (also auxiliaries) and air. On the output side is the product, maybe some by-products which are used for another life cycle as well as all waste, effluents, airborne emissions and excess heat, contributing to environmental impacts. Consequently all quantitative data about inputs and outputs have to be collected in relation to the selected functional (see Section 4.3.2). A special situation occurs if several products are linked in production (see Fig. 4.13), requiring an allocation of impacts. According to ISO the system should be enlarged in such a way that the impacts can be allocated to all existing products, by products, joint production and material. The rules for allocation are also defined, preferably on a physical or an economic basis.

When investigating detailed processes the accuracy and reliability of the inventory data are essential. The most reliable data can be gained when measurements are taken on site, on an operating system with approved settings and formulas. The person collecting the data must have a sound understanding of the nature of the processes and of the consequences if parameters in processing or properties of the product are altered. Mostly this knowledge is not with one person: technical knowledge is in a company and environmental knowledge with the person carrying out an LCA. This requires attentive cooperation and double-checking of information. Where no measurements are available theoretical models of processes have to be generated or data from literature are used. When elaborating an inventory the transformation of the product has to be followed with accuracy: from plant to fiber to yarn to gray fabric and to finished fabric.

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4.12 Scheme for input–output analysis defined for a (central) unit process. The unit process is applied along all chains of the investigated product life cycles.



4.13 If inputs and outputs of a defined process are integrated with other products, allocation rules according to ISO are applied, based on physical or economic contributions to the process.

Inventories are generally shown in Excel format or as an assembly of a software tool. Preferably the inventory is first elaborated graphically in a 'process oriented analysis' (POA), developed by Meyer *et al*. (2005) to ensure a complete data collection. Such graphs can be modeled by means of a software tool (e.g. POA Designer, Visible Analyst, etc.). The software allows starting with a very coarse context diagram of a system and working out the details in several levels by splitting the processes of the level above. Such analysis helps one to understand and control the inventory in detail.

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The following sections give information on data collection for textile production from fiber to the finished fabric.

4.4.1 Cotton growing and ginning

As a functional unit for cotton growing, we can choose 1 kg of harvested fiber or 1 acre (or 1 ha) of cotton growing area. In both cases one has to know how the values are related. Inputs on 1 kg cotton can only be calculated if the corresponding area is known. This emphasizes strongly favoring yield, because all inputs by the farmer are aimed to wards it. The lower the yield, the higher the environmental impacts become. Part of a cotton inventory is given in Fig. 4.14.

Harvested cotton balls are to be ginned, whereby the allocation of the output – cotton seed, cotton fibers and waste – has to be known. The split of these allocation fractions can vary according to the harvesting type (stripper or picker machinery, plugged or handpicked). It is also influenced by the ginning equipment and performance and the natural conditions of the growing area. The ginning processes are exclusively energy driven and highly dependent on the prime energy sources applied for electrical energy,

Assembly:			
Name			Comment
Dryland Functional unit: 1/kg cotton			Acreage: 144 acres (58.3 ha) Yield: 126 lb/acre (141 kg/ha) Total yield: 6.05 tons (5.48 t)
Materials/ assemblies	Amount	Unit	Comment
Diesel	315.12	g	Actions in the field, 497 gal (1881.1 l) Density 0.918 315.12 g/kg cotton
Trifluralin 4EC	18.64	g	1.5 pt/acre (102 l) Assumption: Density 1, 18.64 ml/kg cotton
Cottonseed	71.49	g	9 pounds/acre (391 kg) Variety: HS26, 71.49 g/kg cotton
Caparol 4L	7.77	g	0.625 pt/acre (42.6 l) Assumption: Density 1 7.77 ml/kg cotton
Cyclone	8.64	g	11.6 oz/acre (47.36 kg) 8.64 g/kg cotton

4.14 Part of the inventory (case study A) for calculation with software SimaPro 5.0.

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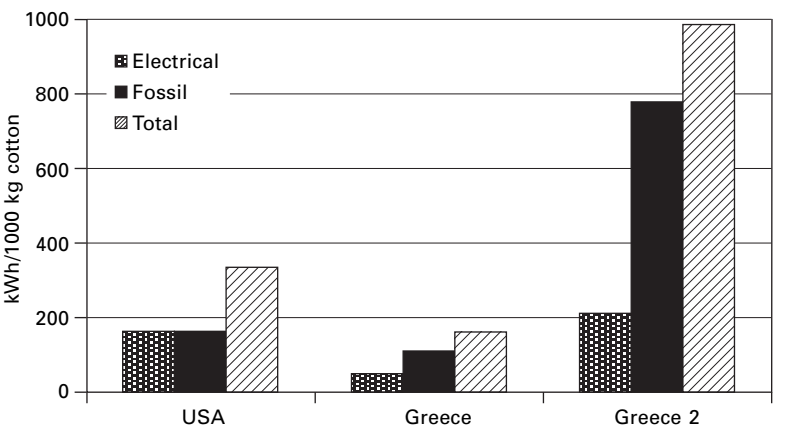
heat and compressed air. Quality and quantity of the output for the paper industry or for agriculture and waste are highly influenced by different factors, from agricultural practices to industrial and legislative parameters of a country. Some examples of energy consumption in ginning are given in Fig. 4.15. These inventories are not further used for LCA because of the lack of national energy data.

4.4.2 Transportation

Before cotton fibers and other fibers are processed in spinning and weaving mills, they are transported over long distances because of the geographically limited growing area. The mix of raw material in spinning processes includes various origins of fibers in Europe, where practically no cotton is grown. Cotton is traded by specific companies. US spinning mills often have their individual suppliers with well-known cotton quality. Table 4.9 shows the calculation of raw material transports for two selected yarn types, one in ring spinning, the other in rotor spinning technology (case study C). The calculation of transportation of a PES yarn is given in Table 4.10. For comparison of products such calculations are necessary.

4.4.3 Spinning, weaving and knitting

In spinning two main technologies are applied: ring spinning and rotor spinning (see Fig. 4.16). The graphical presentation (with Visible Analyst) gives an overview of the main general processes included in these two technologies. These have to be split into unit processes for data collection of the inventory.



4.15 Inventory of energy consumption in gins (three cases) shown as electrical, fossil and total energy in kWh equivalents.

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Table 4.9 Fraction, distance and origin of cotton for ring spun yarn (upper part) and for OE spun yarn (lower part), applied in case study C

Origin	Fraction (%)	Distance by ship (km)	Distance by truck (km)	Distance by rail (km)
Ring-spun yarn				
West Africa	36	6930	870	
Central Asia	18		1880	5120
Israel	20	7630	870	
Greece	13		1600	
Zimbabwe	4	14,130	870	
Paraguay	9	13,130	870	
OE-spun yarn				
West Africa	35	6930	870	
Central Asia	25		1880	5120
Greece	29		1600	
Germany	7		200	
Own combers	4			

Table 4.10 Fraction, distance and origin of polyester applied in case study C

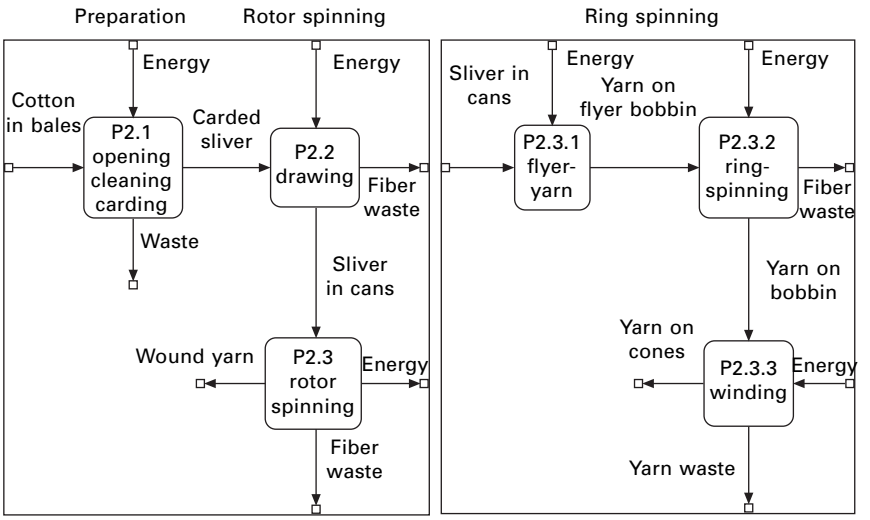
Origin	Fraction (%)	Distance by ship (km)	Distance by truck (km)
Portugal	5		2100
Italy	25		500
Spain	30		1300
France	20		800
Germany	10		2500
Turkey	10	1630	870

For calculation of the inputs and outputs the exact amount of fibers required for the defined yarn has to be set for each individual process, taking also into account all losses according to the spinning schedule.

The inventories C and D are based on measurements of individual machinery and not on average company data. The production of equal amounts of yarns with different fineness does not require equal amounts of process energy. Both inventories include the auxiliary processes of air conditioning and illumination as well as transports of raw fiber material. The weaving inventory data of processes were measured on the site and completed with data from the spinning inventory. Table 4.11 shows a part of the inventory based on measurements on airjet weaving technology for the product in case study B.

Nylon production in case study B was calculated (Kaspar and Kaspar 2000), whereas transportation data were taken from the computer software database (source ETH and BUWAL).

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4.16 Spinning processes and material flows of two different spinning technologies (studies B and C).

Table 4.11 Example of measurements on site for weaving (5% waste)

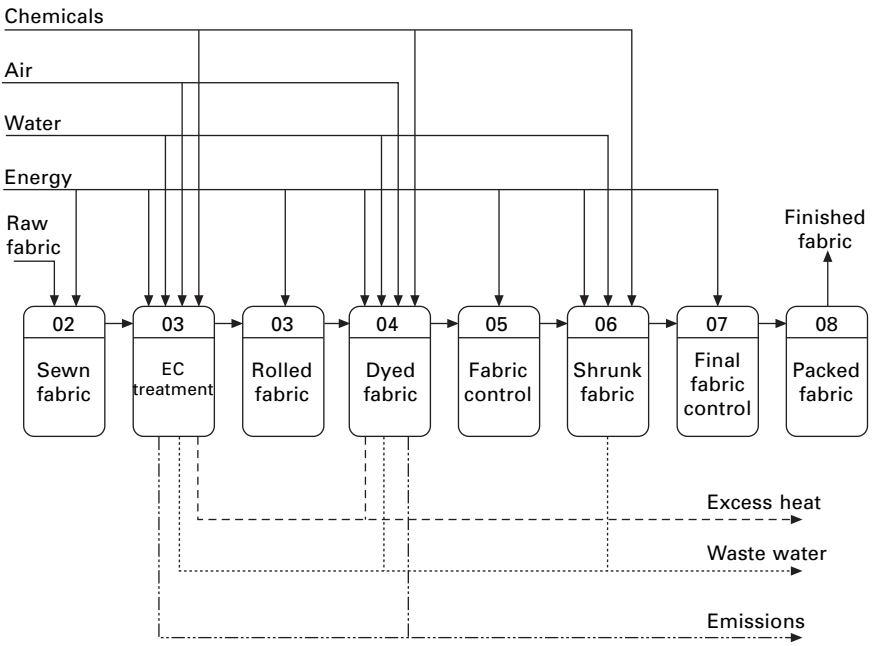
Operation	Equipment/purpose	Energy demand (kWh)
Assembling		0.0007
Sizing		0.0031
Airjet weaving	Sulzer Airjet L5200	0.0351
Air conditioning	Sulzer Airjet L5200	0.2491
Air conditioning	Assembling	0.0007
Air conditioning	Airjet weaving	0.0439
Illumination	Assembling	0.0003
Illumination	Sizing	0.0010
Illumination	Airjet weaving	0.0127

4.4.4 Finishing

The largest product and process variations can be found in finishing. If the LCA is used for comparison of different products we may take 1 m^2 as the functional unit, but for comparison of process technology also an average batch is taken, allowing the optimization of the company's order structure.

Figures 4.17 and 4.18 show the different inventory structure for fabric L, a fabric for leisure trousers, and fabric M, a fabric with higher requirements for medical workwear (case study E). Due to the two fiber types in fabric M, two dyeing processes have to be carried out in series and the precise setting of dimensional stability requires additional processes with different process technology.

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4.17 Finishing processes and material flows for fabric L in case study E.

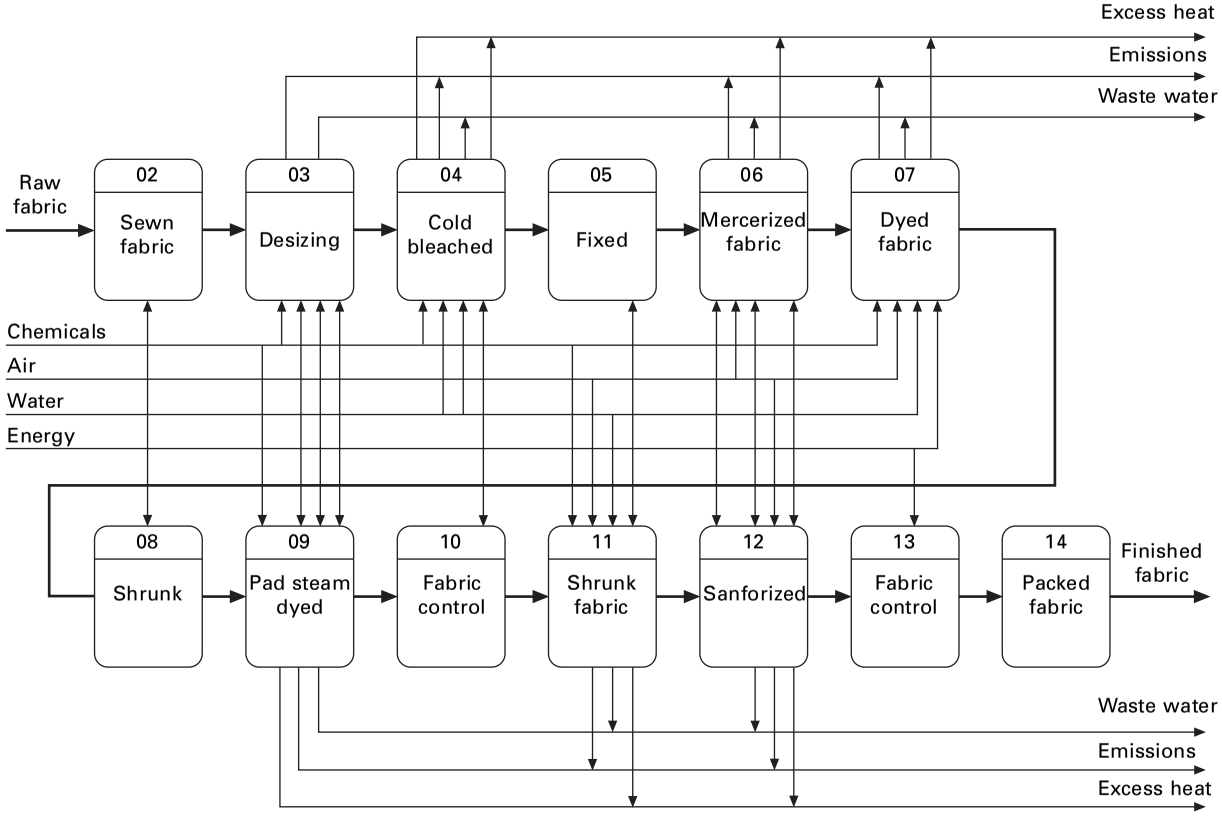
Table 4.12 gives selected details from the inventory of case study D, specified on processes. Some input chemicals are applied only in small quantities, but prove to have a high impact on the environment. However, a comparison of the inventory (LCI) and the impact assessment (LCA) results shows that the amount in the inventory (measured in kg or liters) does not define the degree of the impact (see Fig. 4.19).

4.4.5 Manufacturing

Even through manufacturing is a production process, there seems to be no point in doing it to carry out LCA studies at a product level. The inventory would be based on cutting and a large number of sewing and assembly processes, each product being unique not only in the inventory but also in terms of quality and function. However, in case study G a simple inventory was elaborated, based on a model for the working environment including heating, water and illumination as well as electrical energy of an industrial sewing machine for a functional unit of 1 kg PES T-shirts. Companies often have figures for their annual production and their output unit is manufactured pieces.

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4.18 Finishing processes and material flows for fabric M in case study E.

Table 4.12 Part of inventory data (LCI) from case study D. The arrows indicate small amounts of hazardous substances. These facts give evidence for an impact assessment (LCA) instead of a simple inventory (LCI)

Emissions to warer	Unit	Pre-treatment	Dyeing	Finishing	Article	
Nitrogen	g	64.292	2.309	0.057	0.022	
TOC	g	5687.541	27.093	42.383	0.116	
COD	g	39,213.58	7379.083	0.124	0.032	
BOD_5	g	12,661.686	2868.760	0.006	0.001	
AOX content	g	0.005	0.381	1.000E-04	4.902E-05	←
DOC	g	0.387	3.223	0.614	2.000E-04	
Sulfur	g	1457.040	0	0	0	
Zinc	g	0.110	0.105	0.042	0.004	
Toluole	g	0.159	0.131	0.011	0.001	←
Dispersed substances	g	104.813	83.073	45.652	0.806	
Sulfide	g	0.042	0.035	0.001	4.000E-04	
Sulfate	g	150.804	143.384	54.654	5.603	
Organic nitrogen	g	0.482	0.3983	0.007	0.004	
Radioactive substances	kBq	1162.113	1130.652	443.429	48.153	
Mercury	g	1.039E-04	1.000E-04	1.430E-04	4.414E-07	←
Phosphate	g	0.343	0.324	0.146	0.013	
Phenol	g	0.179	0.148	0.011	0.002	

4.4.6 Laundry (use phase)

The laundry processes refer to professional laundry as a textile service and include as an inventory washing processes as well as three options for drying of individual products: mangling (flat textiles), tumble drying (polar textiles) and tunnel finishing (apparel) (see Fig. 4.20).

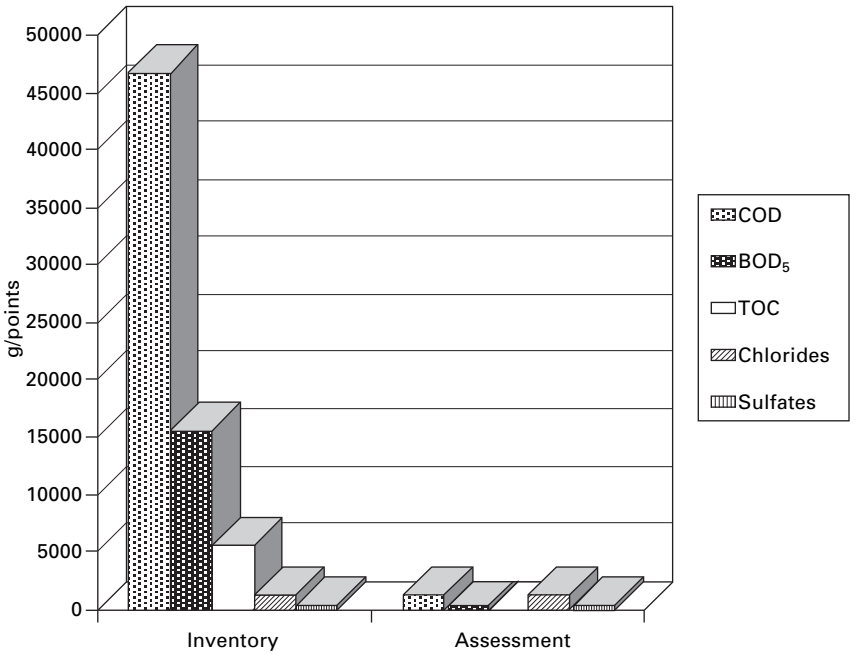
The inventory also includes some auxiliary processes carried out in the company: pre-treatment of water, air compression and steam production. The graphical representation of the washing and drying processes is shown in Fig. 4.21 and 4.22. Case study E also provides a future scenario based on the idea of replacing private laundry by professional laundry. Data for private laundry are taken from Affolter and Steiner (2002) and completed with a model for transportation service in a town.

4.4.7 Recycling

Each country within Europe has established its own recycling system for textiles and apparel fractions, combined with the general municipal waste management. Figure 4.23 presents the apparel recycling system in Switzerland.

Often textiles of different fibers are collected and sorted for reuse and disposal or incineration (Maechler *et al.* 2004). Man-made fibers can technically

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4.19 Comparison of LCI data (in grams) and LCA data (in points) of a finishing formula (case study D).

be recycled to the original monomer form. A particular case represents the relatively small fraction of nylon products in the fiber application, which is related to the plastic applications of the material and through this offers interesting options for reuse, remanufacturing, etc. (see Fig. 4.24). The actual material flows of Nylon 6 have been investigated in case study H (see Fig. 4.25).

4.5 Life cycle assessment (LCA) results

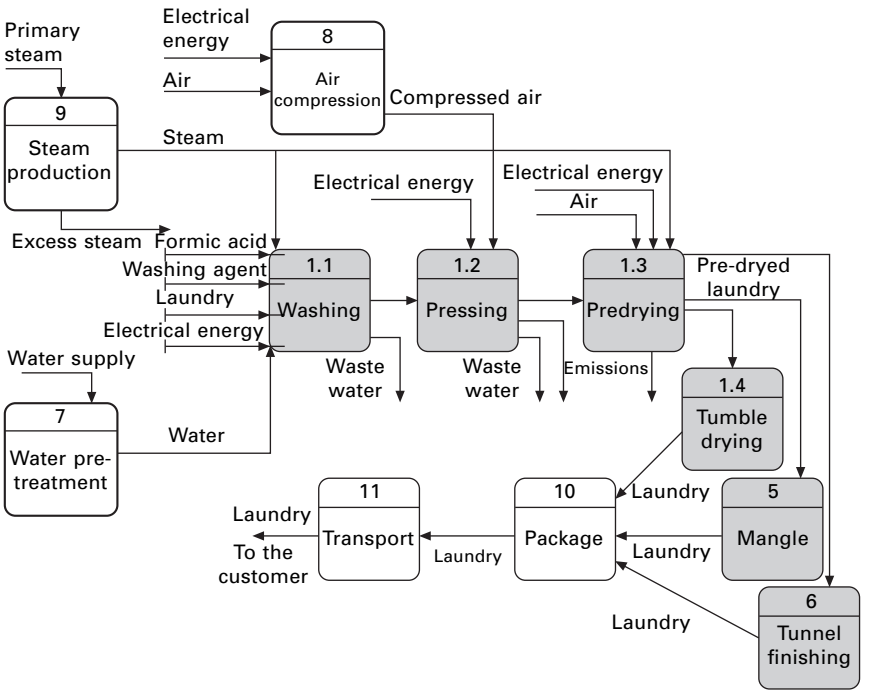
In this section the results of the eight case studies for textiles and textile processing are presented (see Section 4.2).

4.5.1 Case study A: Cotton growing

Selected irrigation systems (see BAT in Chapter 3) and dryland cotton cultivated by different farmers show differences in yield (see Section 4.4). Yields ranged from 100 lb/acre ('BDryland') to 1300 lb/acre ('WRR'). In our study we found the LEPA irrigated 'WRR' scenario, cultivated on the same farm, best yielding, followed by 'BFurrow', 'BLEPA' and 'BDryland'.

As expected, the growing scenarios also require different amounts of

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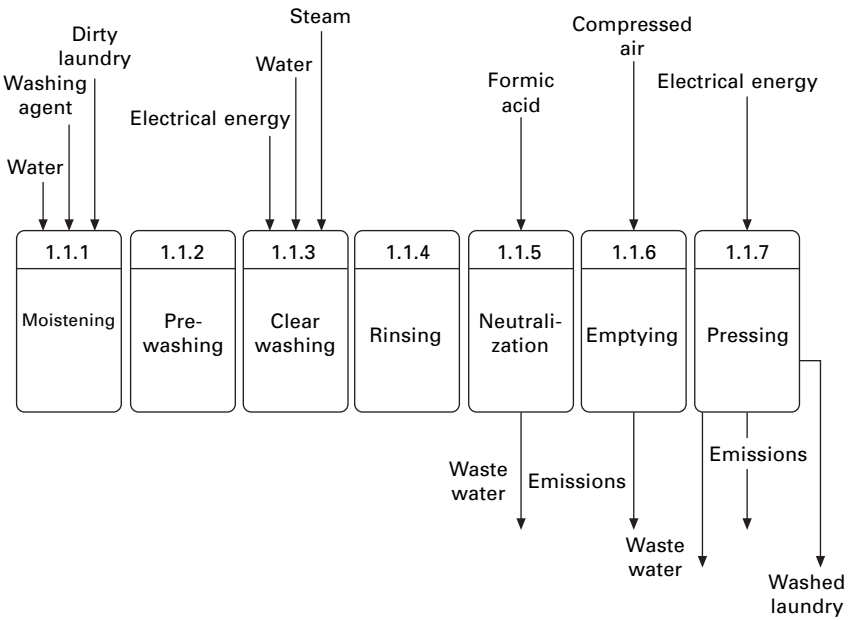
4.20 Laundry processes and material flows for the professional laundry process of case study F. Processes 1.1, 1.2, 1.3, 1.4, 5 and 6 are primary processes (gray). Steam production, air compression and water pre-treatment are auxiliary processes included in the system.

water (see Chapter 2). The same farmer cultivated the scenarios 'BDryland', 'BLEPA' and 'BFurrow', while 'WOrganic' and 'WRR' were cultivated by another farmer. The comparison between the two LEPA scenarios indicates differences generated by the different farmers (practice) and different sites (weather conditions). The water consumption may not be considered without reference to the yield (see Section 4.4).

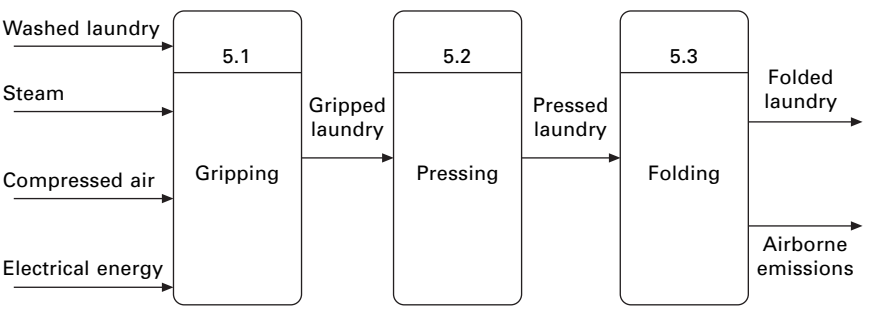
The most important factor for the farmers is cost per kg cotton (see Section 4.7.2). The presented LCA results of the growing scenarios BDryland, BFurrow, BLEPA and WLEPA (Figs 4.26–4.29) all show the great impact of pesticides applied. Consequently WOrganic (Fig. 4.29) shows lowest impacts, followed by WRR (Fig. 4.28 insert) with a 300 times higher impact. Next best scenarios are BDryland (Fig. 4.26), BFurrow (Fig. 4.27) and BLEPA (Fig. 4.28), all a factor 1000 times higher than WRR and a factor 300, 000 times higher than WOrganic. The impacts are focused on ecotoxicity, since no other impact category indicates a significant impact.

Regarding irrigation systems, the differences are almost irrelevant, especially if we compare the two LEPA systems WRR and BLEPA (Fig. 4.28), where

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4.21 Detailed sub-processes and material flows for the washing process 1.1 (see Table 4.12) in case study F.

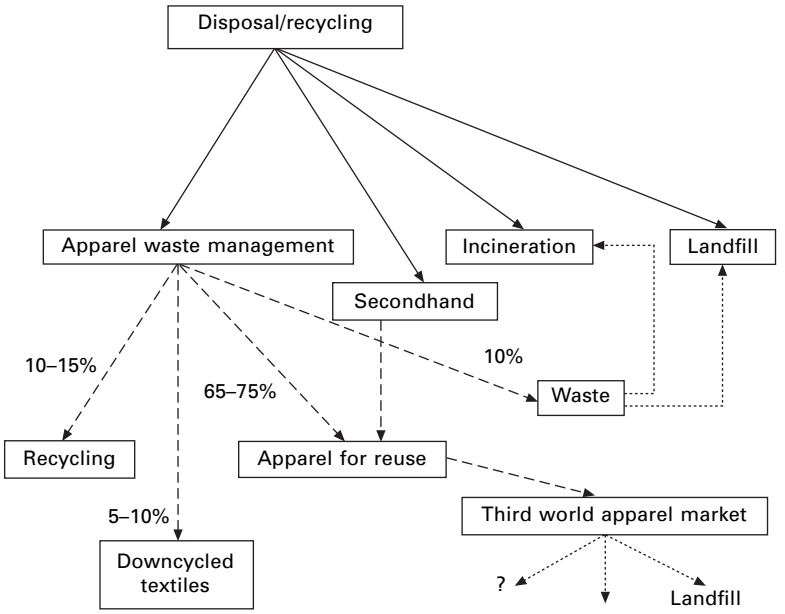


4.22 Detailed sub-processes and material flows for the mangling process 5 (see Table 4.12) in case study F.

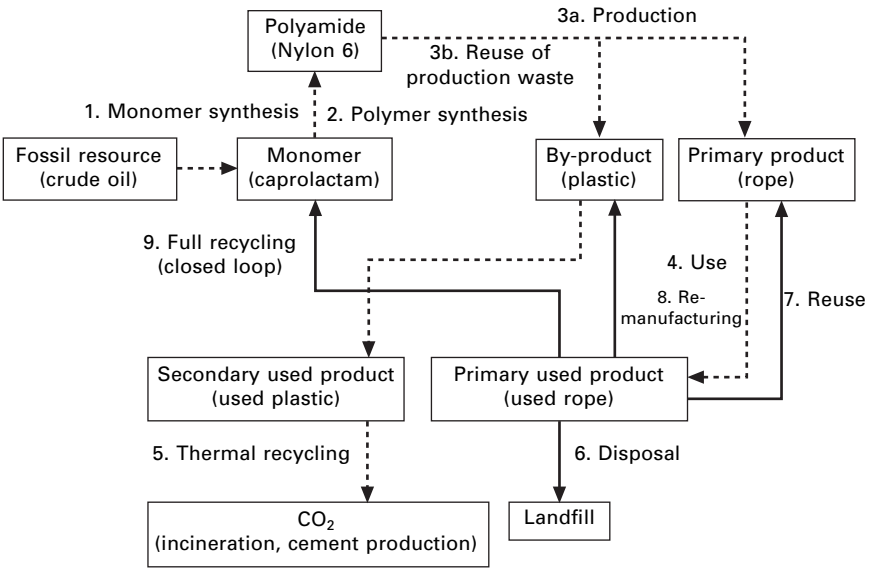
environmental impacts show a difference by a factor of 1000. In BDryland the impact is caused by Fyfanol UL mit, while in DFurrow and DLEPA the impact of Fyfanol mit is surpassed by that of Thimet 20G mit. In the second LEPA system, cultivated by a different farmer, WRR Cyclone mit followed by Trifluralin 4EC mit cause the impact.

All other impact categories – greenhouse, ozone layer, human toxicity, eutrophication, acidification and summer smog – mark only marginal effects compared to ecotoxicity. Comparison of the two LEPA systems shows that in

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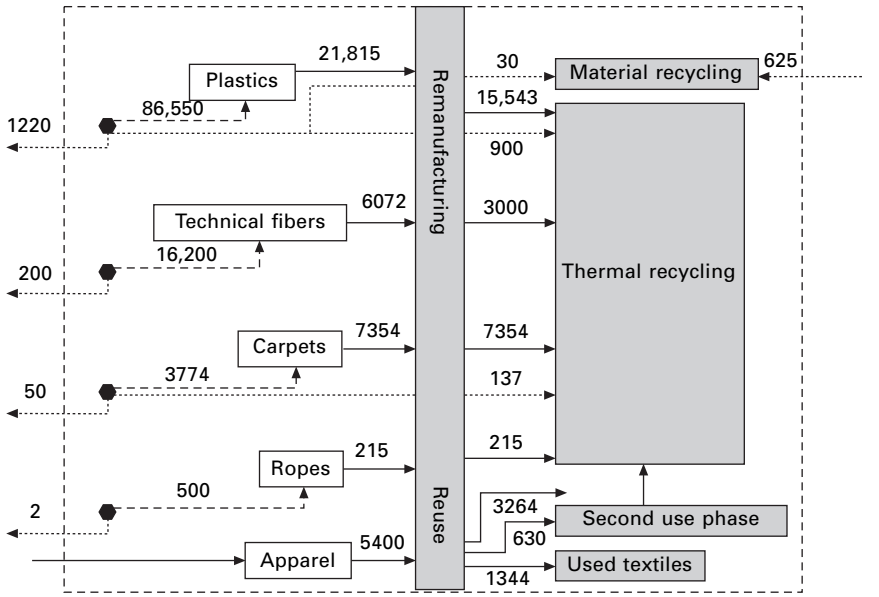


4.23 Options for material flow of apparel recycling. Each country has developed an individual recycling system whereby available recycling technology and/or options for reuse are taken into account. The numbers for apparel management are based on information from Swiss textile recycling companies.

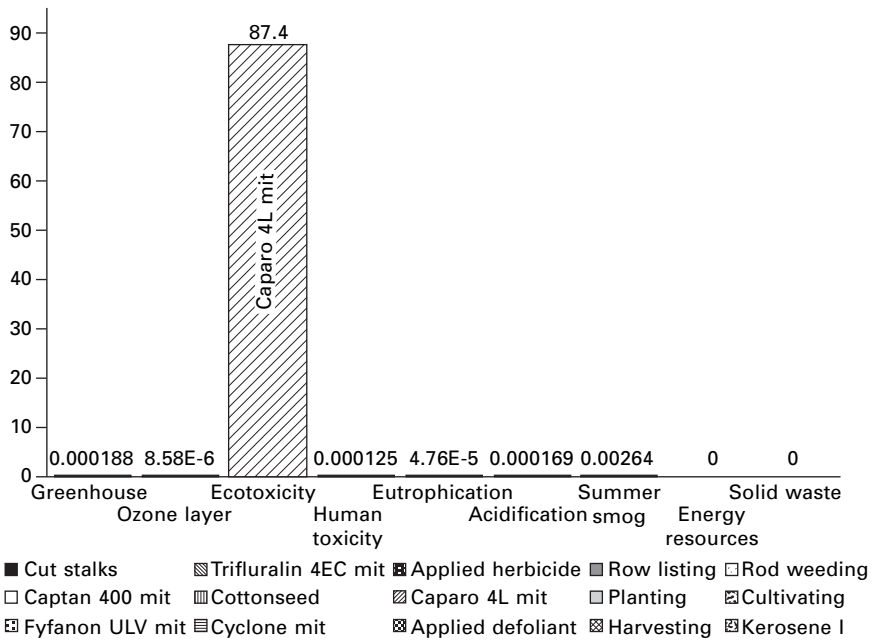


4.24 Options for material flow of nylon recycling in Switzerland. Some options require international transportation for economic reasons such as productivity of a plant (see also Fig 4.23).

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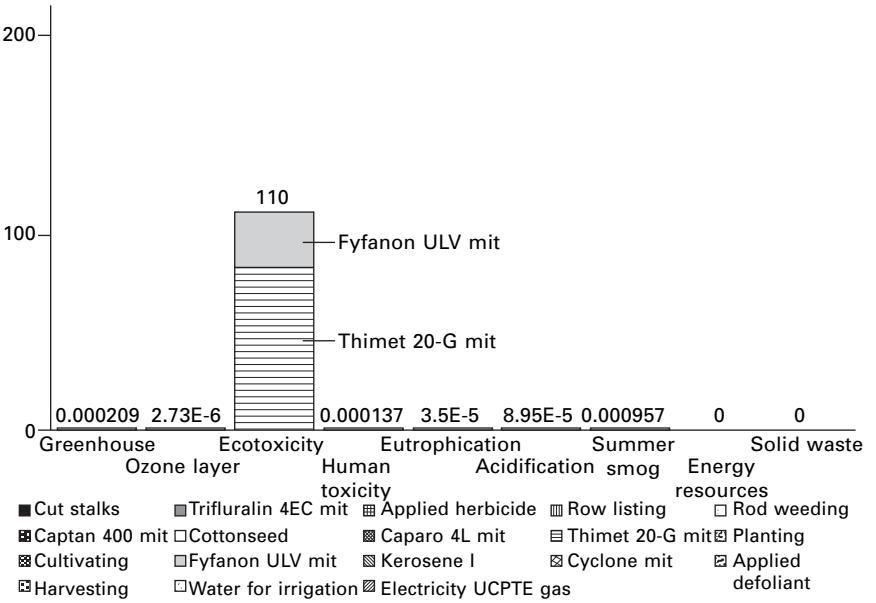


4.25 Product-specific polyamide flows in Switzerland (gray area), imports and exports.



4.26 LCA results (in millipoints) of dryland cotton (method CML) of case study A.

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4.27 LCA results (in millipoints) of furrow irrigated cotton (method CML) of case study A.

the WRR little pesticide is applied. Consequently impacts caused by energy production and for application become relatively more important.

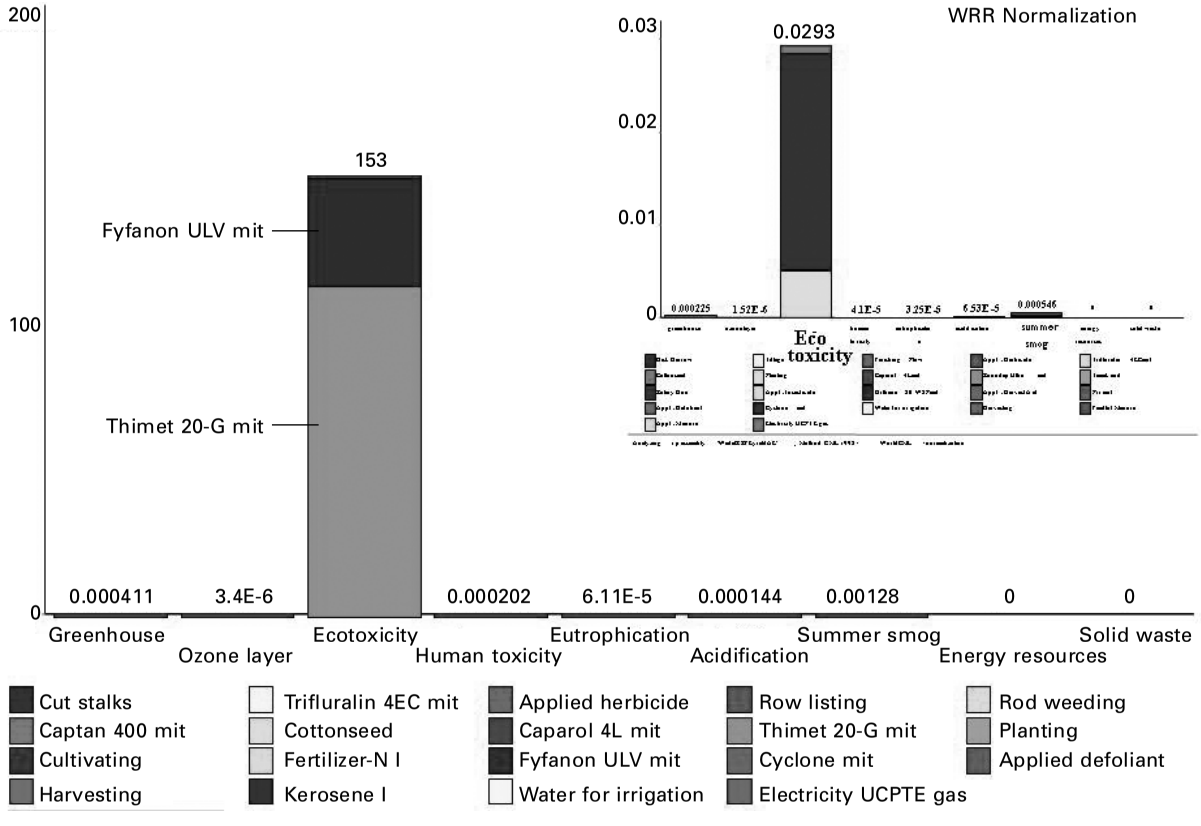
Only in WOrganic (Fig. 4.29), where no pesticides are applied, do other impacts than pesticides become relevant. The impacts, however, are a factor of 10,000 times smaller than in all growing scenarios cultivated by farmer B (see also Fig. 4.28). The impact categories ecotoxicity and summer smog are mainly affected, followed by greenhouse. The effects are mainly caused by the manure applied and the gas used as energy source.

The presented results do not allow a ranking between irrigation systems. The highest differences between systems are by a factor of 2 (Figs 4.27 and 4.28), while differences between practices of individual farmers with the same system show a factor of 1000 (see Fig. 4.28). Consequently, individual management practices prove to be the most important influence on impacts. In Fig. 4.28 the effect of a GMO variety becomes visible, since WRR affords much less pesticides compared to the same variety grown with the same irrigation system. In BLEPA a considerable amount of pesticides was applied. Because the Roundup Ready variety (WRR) was grown by a different farmer, the effect of good management practices and the GMO cannot be proved independently.

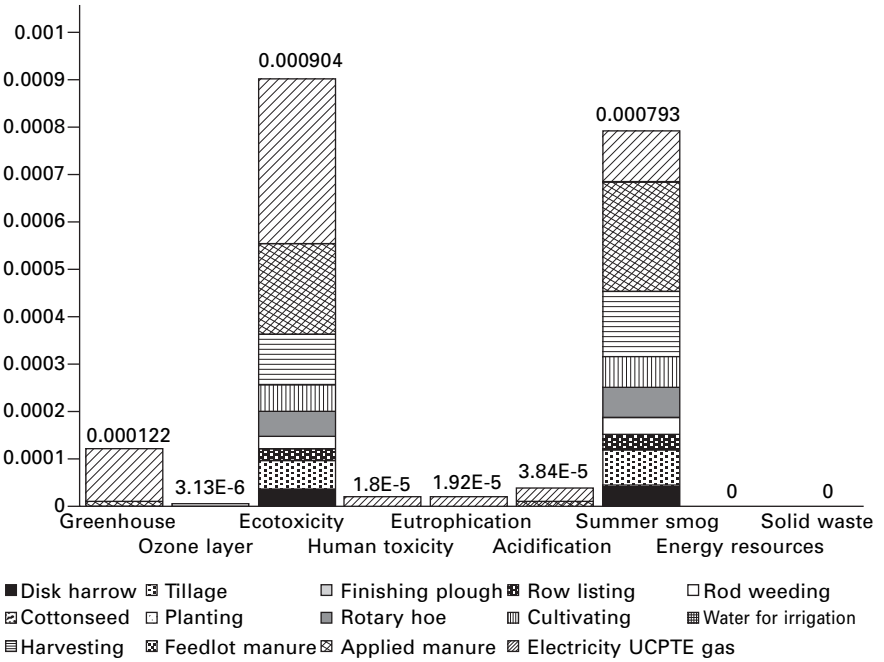
A complete LCA normally includes all impacts of pesticides from production to effect. Figure 4.30 shows the differences for Malathion, whereby all impacts are compared to production (100%). Application includes all mechanical

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4.28 LCA results (in millipoints) by two different farmers with LEPA irrigated cotton (method CML) of case study A. The differences indicate that good farming practice leads to better results.



4.29 LCA results (in millipoints) of LEPA irrigated, organic cotton (method CML) of case study A. The impacts are a factor 500 times lower than those of a conventional cotton grown by the same farmer (see Fig. 4.28 insert).

work for the application of the field, except the substance itself. The latter is represented by the effect.

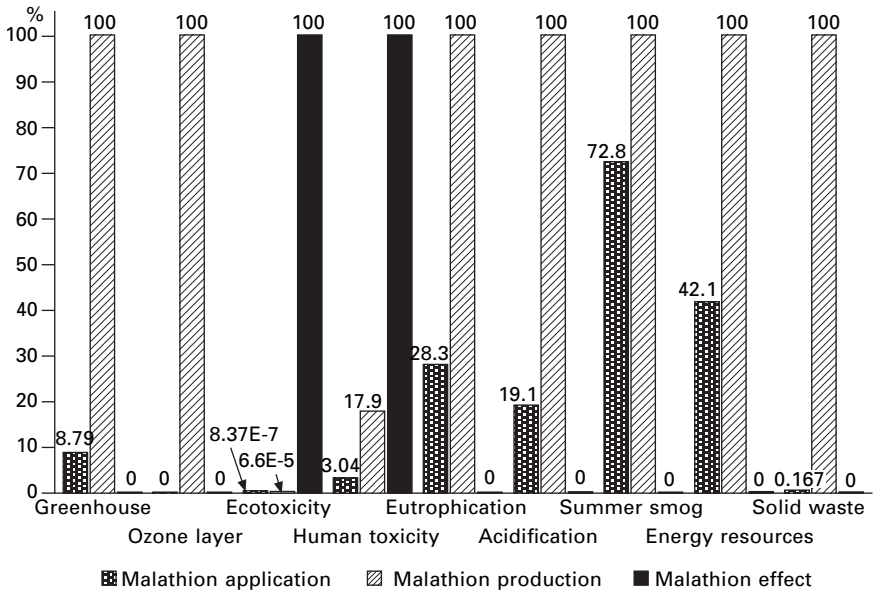
The example of the pesticide Malathion (Fig. 4.30) indicates that impacts in production exceed the impacts of application and effect. This relation is not given for every pesticide and is highly dependent on the application type. In the case of Trifluralin the relation is inverse (not shown here). Generally the part of agrochemical production is not included in this system. (Source: Tobler and Schaerer 2002)

4.5.2 Case studies B and C: Spinning and weaving processes

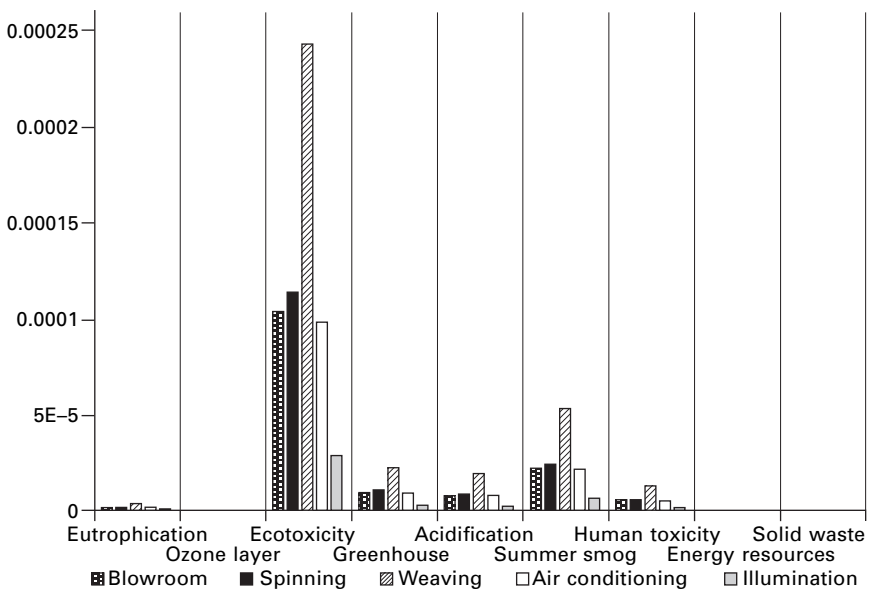
The results of study B are presented either in the CML method by means of different impact categories or as EcoIndicator points.

The main impact categories with the CML method for the production of OE jeans fabrics are acidification and heavy metals, followed by winter smog (see Fig. 4.31). The highest impacts are caused by overseas transportation and spinning (blowroom and spinning) and weaving processes (Fig. 4.32),

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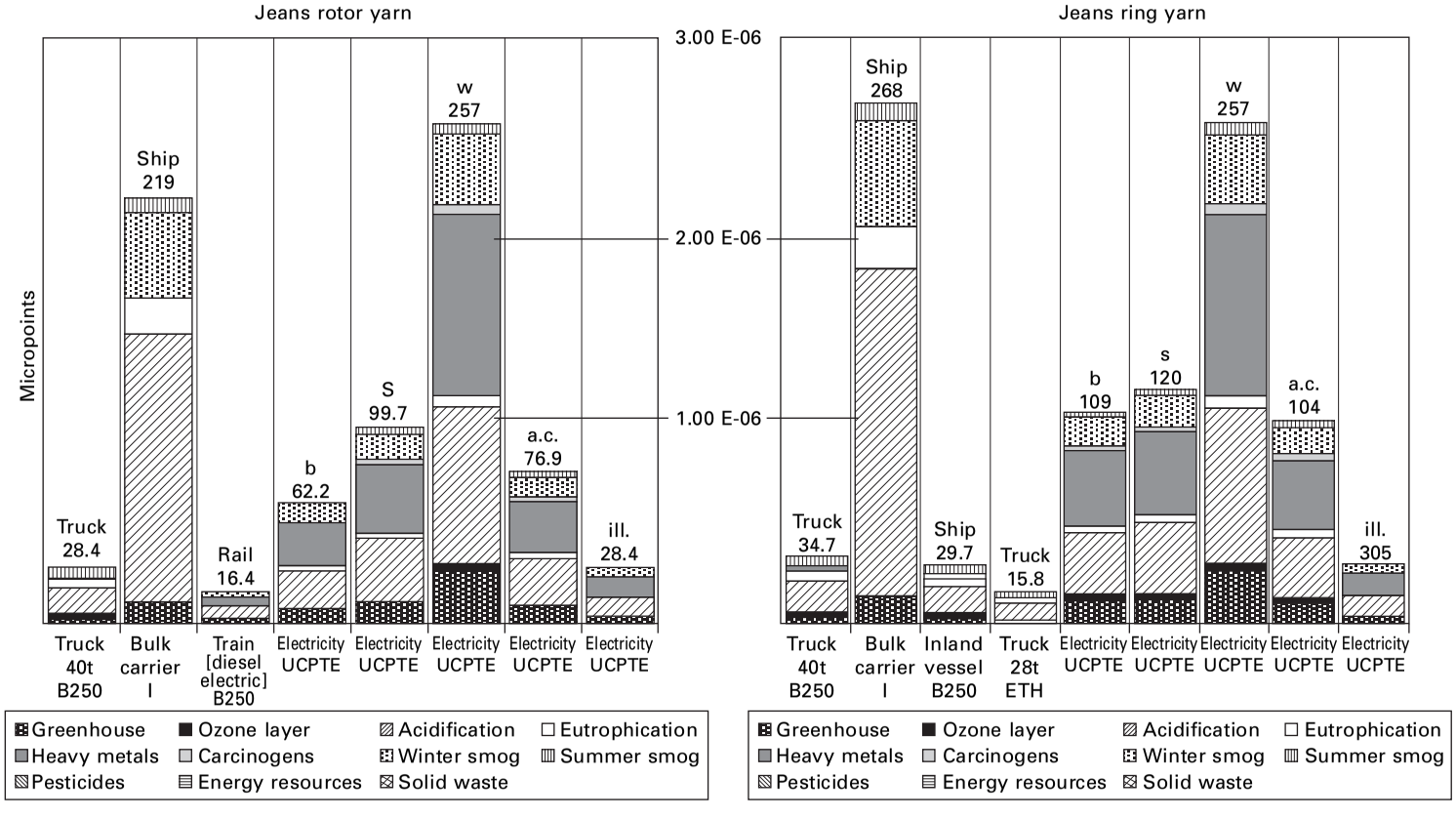
4.30 Example of the life cycle of an agrochemical (not included in case study A results). In this particular case the impacts by production exceed the impacts by application and effect. This relation cannot, however, be generalized for all agrochemicals.



4.31 LCA results (method CML) for production (spinning and weaving) of a jeans fabric (study B).

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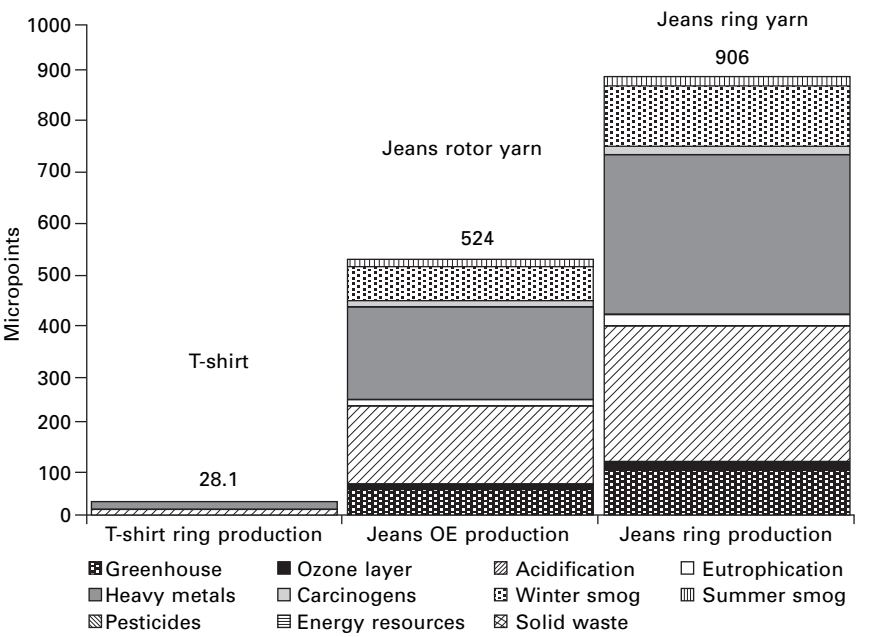
4.32 LCA results (method CML) of a rotor-spun jeans fabric and a ring-spun jeans fabric in spinning and weaving (case study B). The raw material is transported with different transport systems.

whereby the impact caused by air conditioning is considerable (method EcoIndicator 95). A comparison of fabrics (per m^2) produced with different spinning technologies and knitting technology shows the ranking of impacts: ring-spun jeans, OE-spun jeans, knitted shirts, whereby the lower weight of the knitted fabric has to be taken into account. Even with equal weight, the knitwear causes lower input.

Different continental transportation methods (truck/inland vessel or railway) cause smaller changes than different spinning technology, the latter influencing also air conditioning.

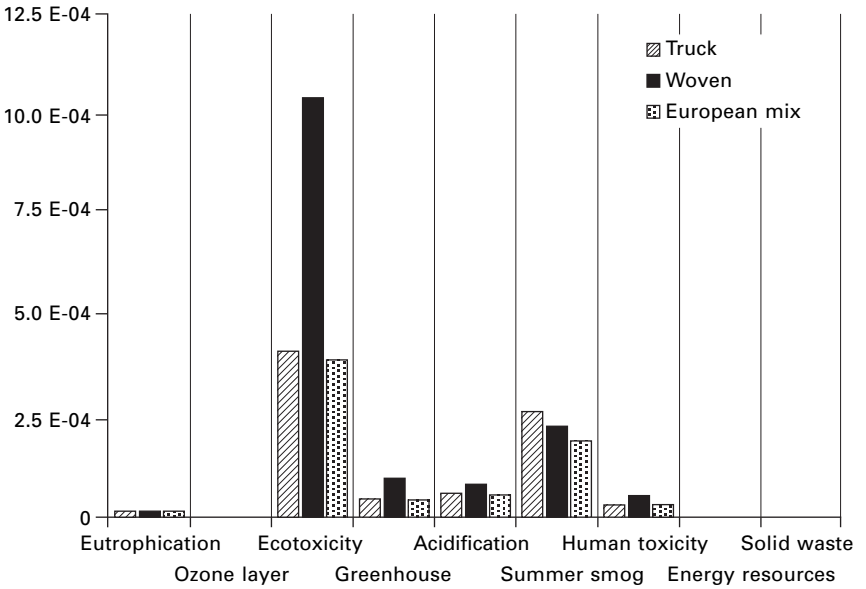
The production of a tissue with high warp density causes only two-thirds of the impacts of a tissue with high weft density, due to the high energy consumption of the air injection. Impacts can be lowered if OE spinning technology is applied instead of ring spinning. Knitting technology (T-shirts) causes a very low impact, whereby the lower fabric weight has to be taken into account (Fig. 4.33).

Figure 4.34 shows the magnitude of environmental impacts between knitted and woven (T-)shirt production, if truck transportation is used instead



4.33 ILCA results (method EcoIndicator 95) for 1 m^2 of a knitted product (T-shirt) and two woven products (jeans), produced by two different technologies. As the energy life cycle is included in the system, the low impact of the knitted fabric is achieved by both the knitting technology and hydropower energy (production on the plant).

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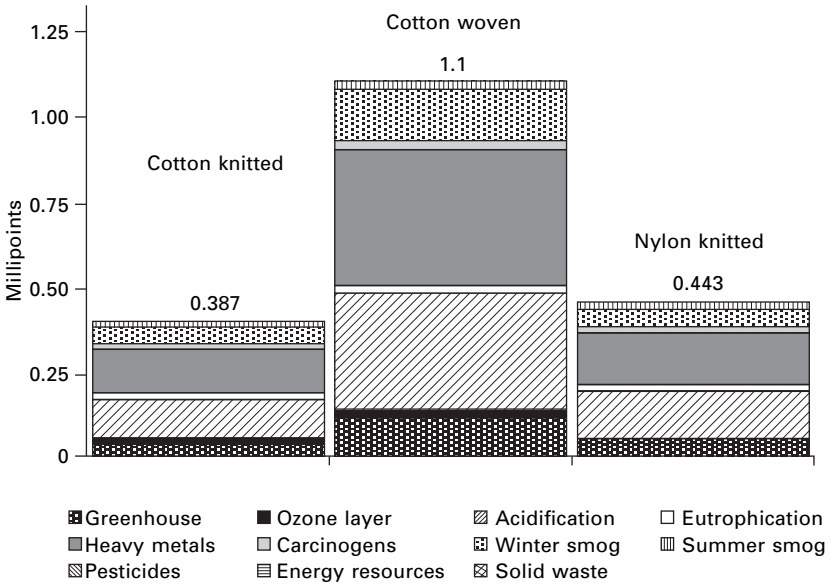


4.34 LCA results (method CML) for production (transportation, spinning and knitting/weaving energy source) of a T-shirt (case study B) with variations: truck (transportation by truck, spinning and knitting energy source: national mix), woven (transportation by train, weaving instead of knitting, national mix) and European mix (transportation by train, spinning and knitting energy source: European mix). The impact of truck instead of train is comparable to the use of national mix instead of European mix for the energy source.

of railway and if a European electricity mix is used instead of a national mix. Consequently the influence of process technology is the highest. If the question were to select a technology causing lower impacts, this would favor knitting technology compared to modern airjet weaving technology. For main applications (commodity fabrics with fine and medium yarn fineness) the advanced four-phase weaving technology is applied, as shown in case study C. This very advanced weaving technology is more environmentally friendly than conventional knitting technology, also due to its higher productivity. In practice such a statement may become irrelevant regarding the number of parameters defining properties of knitwear and woven wear, but the fact can be taken for practical guidelines in product development and production. Process technology (woven versus knitted) also proves to have more impact than changes in raw material (cotton and nylon) (Fig. 4.35), for which literature data were taken for cotton growing and a calculation model was applied for nylon production.

In study C a comparison of production, infrastructure and administration

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4.35 LCA results for three variations of T-shirts. The difference between knitting technology and weaving technology is much higher than the difference caused by the fiber type.

processes per m^2 of fabric was carried out, indicating that administration and infrastructure make only very small contributions (Fig. 4.36). This is shown in detail also for the OE yarn (Fig. 4.37), allowing one to conclude that inventories based only on production data are accurate enough, especially if they are used for company-based product development. An interesting finding is the lower impact caused by the different weaving technology of 81 micropoints compared to 250 micropoints (see Fig. 4.29) in the EcoIndicotor 95 method.

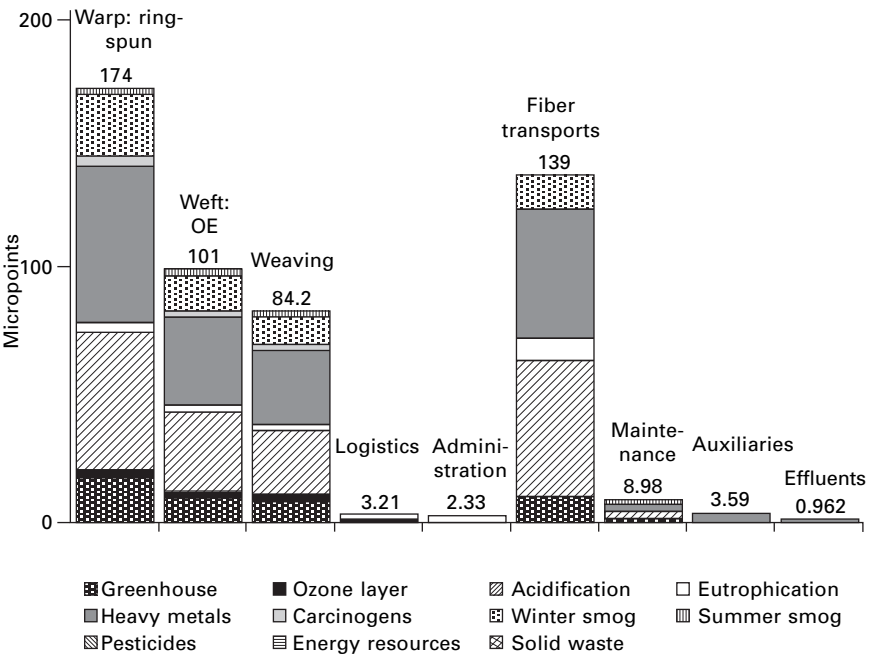
Figure 4.38 shows the differences of impacts if fiber production (cotton or polyester or both) is included in spinning and weaving per m^2 fabric.

This leads to the conclusion that fiber production influences the environment more strongly than the production processes. If polyester production is integrated, the impact increases from 0.517 millipoints to 1.77 millipoints (by a factor of 2.7); with cotton production the result increases by factor of 2.1 (method EcoIndicator 99).

4.5.3 Case studies D and E: Finishing processes

The first step in case study D was a detailed LCA of a given formula (B2 in Table 4.7) with addition of a print process (B3) and thereby including all general finishing processes of a cotton fabric. The aim was to learn about the

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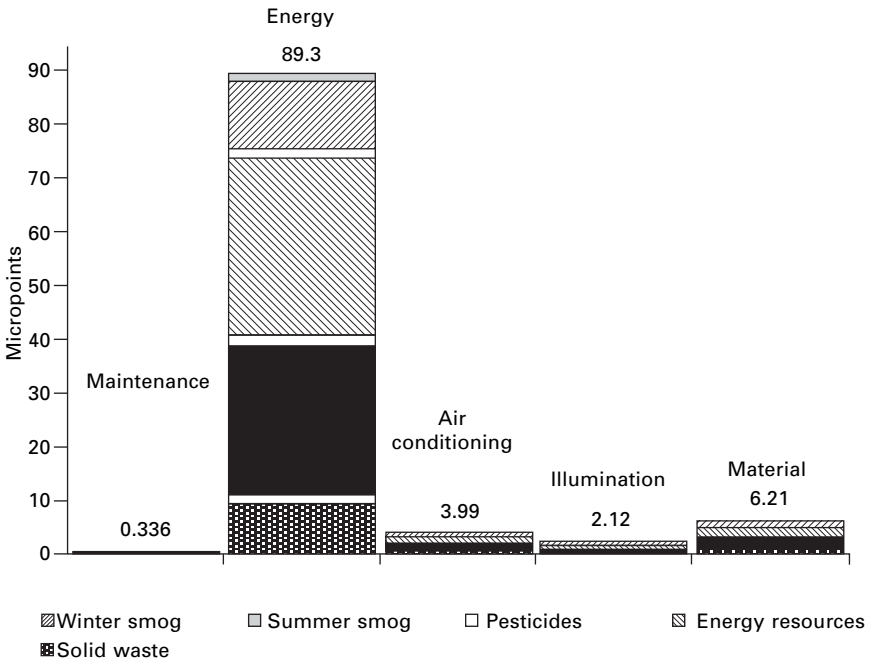
4.36 LCA results for the processes of case study C. The low impacts of administrative, logistical and maintenance processes as well as auxiliaries and effluents indicate they can be neglected for a streamlined LCA.

magnitude of impacts if individual finishing processes, individual technologies and individual formulas are applied. The calculation of a process, based on the inventory with the CML method, allowed one to associate the main impact to individual processes. Process technology has been evaluated as very advanced, including heat recovery and neutralization by means of CO_2 from airborne emissions. Bleaching and dyeing processes of the knit were carried out on a pad system with cold fixation, an energy saving technology, which requires careful process control of the knitted fabric in order to avoid dimensional changes. Printing was carried out on modern 12-color rotor print equipment. Finishing consisted of a Sanfor® process.

The result of the given formula (Fig. 4.39) shows that the printing process causes by far the largest impact, whereby eutrophication, acidification, human toxicity, energy and greenhouse effect were mainly affected. On a much lower level mercerizing followed by the dyeing process contribute to the environmental impacts. Whereas the mercerizing process does not offer many options, the dyeing process includes a variety of process technologies and formulas.

In a simplified approach (simplified LCA), only eutrophication and energy

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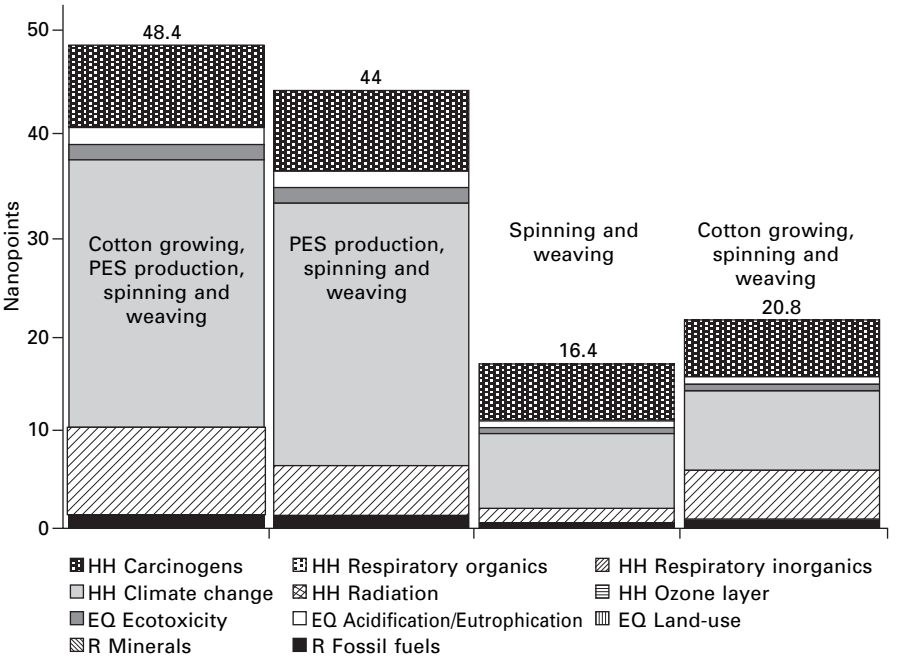


4.37 Detailed LCA results for production of a rotor-spun yarn.

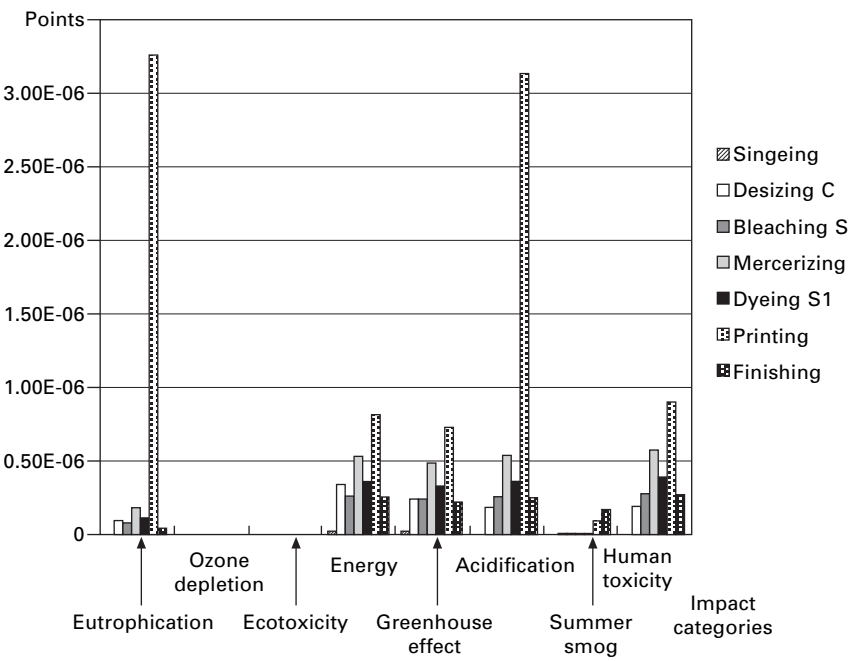
consumption are evaluated. As shown in Fig. 4.40 variation factors were dyestuffs (B1 and B2), dyeing technology (B1, B2, A2 pad, A1 exhaust) as well as the number of rinsing/drying processes (B1 and B2 none, A1: 1 and A2: 2). The results show minor differences in eutrophication due to different dyestuffs. Additional rinsing and drying processes require more energy (Al and A2). Due to the cold fixation with the pad system this technology requires less energy than exhaust technology, but exhaust technology causes little less contribution to eutrophication due to the auxiliaries applied in pad system dyestuffs application. Additional rinsing processes may become necessary for quality reasons in order to prevent remaining chemicals from interfering in the succeeding process (see Chapter 3). The inventories for these results have been collected in two different companies A and B, indicating also differences based on company performance and products.

A considerably higher impact occurs if not only central processes (as calculated for Fig. 4.36) but also energy supply is considered. The general differences caused by the prime source are given in Fig. 4.41 where a scenario of 100% crude oil, a split of 60% oil with 40% gas, and 100% gas are calculated for. All results highly depend on the energy and water management of a company as shown in Fig. 4.42, whereby especially the category summer smog is affected. Such differences can be explained with

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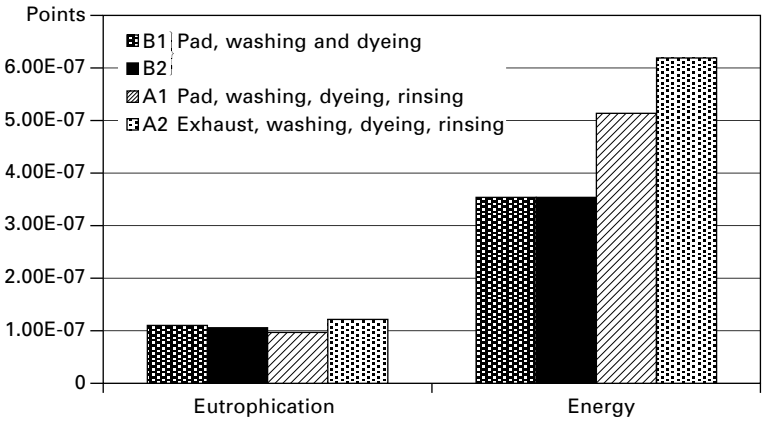


4.38 Detailed LCA results for production of a rotor-spun yarn. Data for fiber production are taken from the literature.

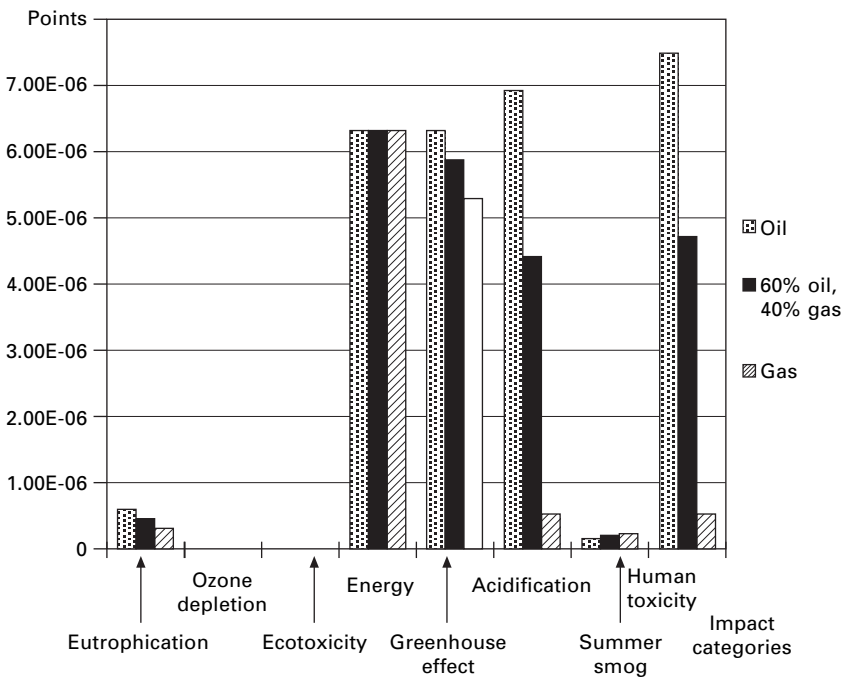


4.39 LCA results of a finishing formula (case study D).

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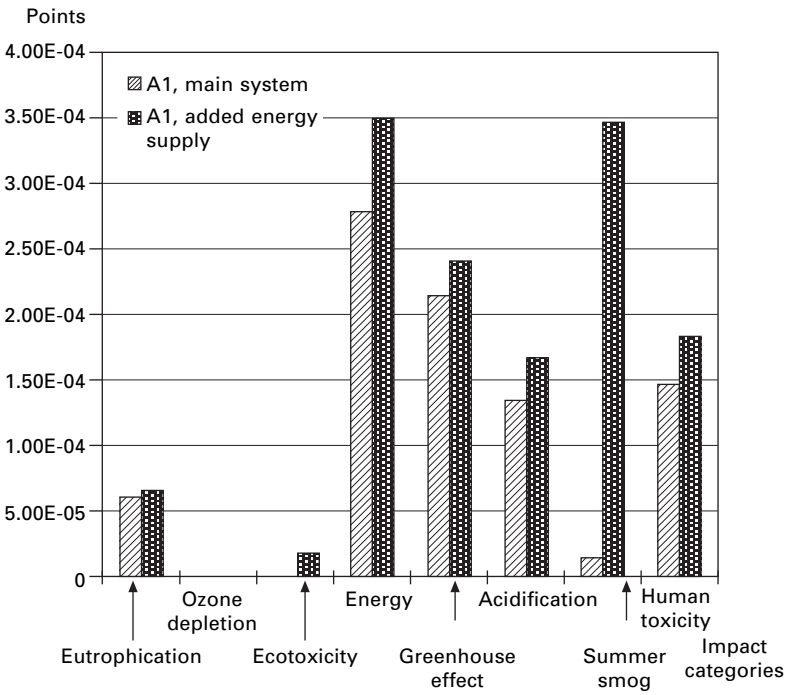
4.40 Results of different finishing technologies and processes (simplified LCA) from two companies A and B (case study D).



4.41 Scenarios for different prime sources (energy) in finishing (case study D).

system modeling. For company product development this may be of minor interest, but taking finishing as a part of textile production it must be included in the system. (Source: Tobler 2005a).

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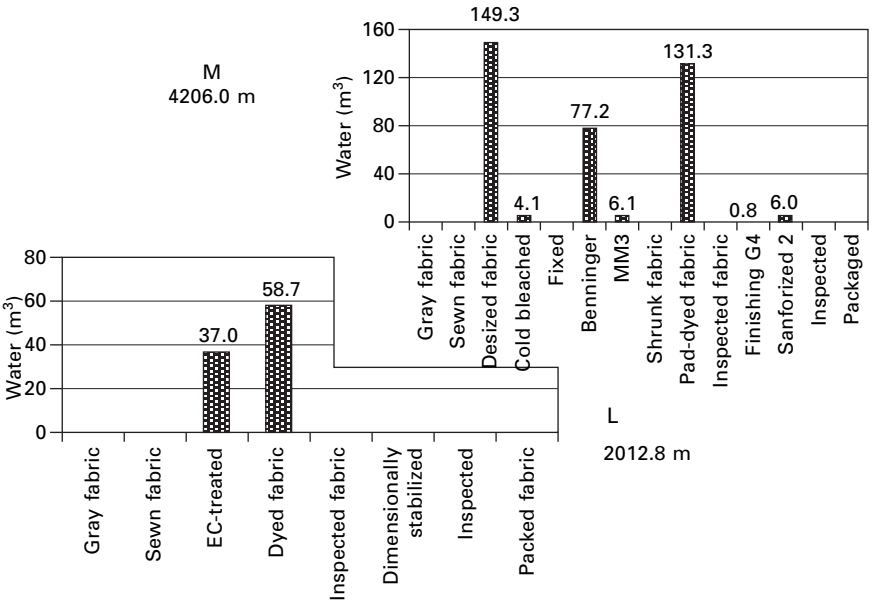


4.42 LCA results for a finishing formula (case study D) shown with the influence of system modeling (method CML), with and without the auxiliary process energy supply.

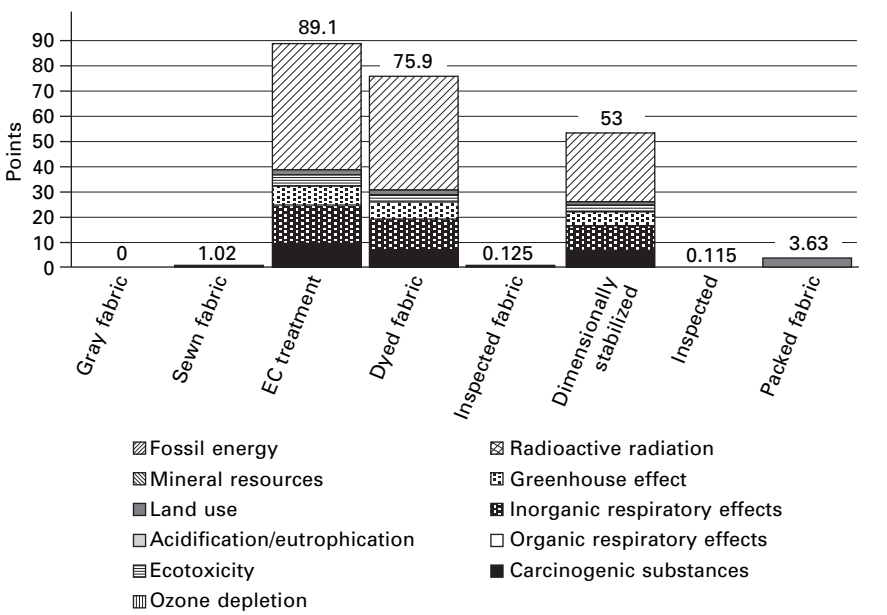
Case study E is focused on two different products, finished by the same company. The energy and water management is completely different from those in case study D, and also different for the two products M and L (see below). Most interesting is the production of electricity as a by-product of steam production from coal. The energy, water and effluent management of the company have been included in the calculation on a basis of average annual consumption related to the output.

The two fabrics, M for medical working wear and L for leisure, are compared as batches of an average, product-specific length. The number of processes for M is increased because of the desizing process for cotton and because two fiber types have to be dyed in separate processes. Consequently the water consumption of batch M of 90 liters per meter must be higher than that of L with 50 1/m, shown as batch consumptions of the individual processes in Fig. 4.43. The full process LCA of L shows main impacts in the combined pre-treatment (EC) and in the dyeing process as well as in the finishing process for dimensional stability, whereby the categories fossil energy and inorganic respiratory effects, followed by carcinogenic substances, are mainly affected (see Fig. 4.44). The level of these impacts per batch (2013 m) is between 50 and 90 points.

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4.43 Water consumption of the two fabrics M and L in finishing (case study E).

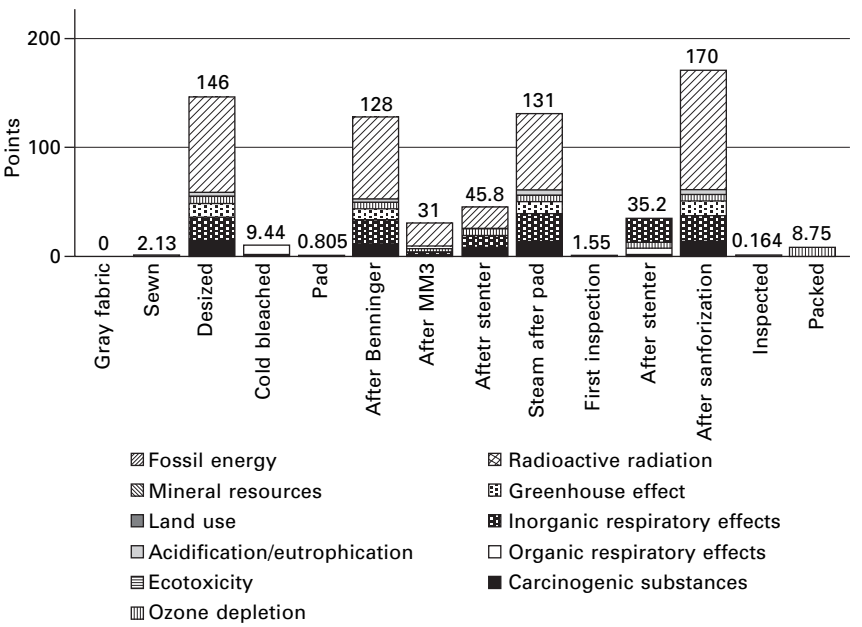


4.44 LCA results of the finishing processes for fabric L (case study E).

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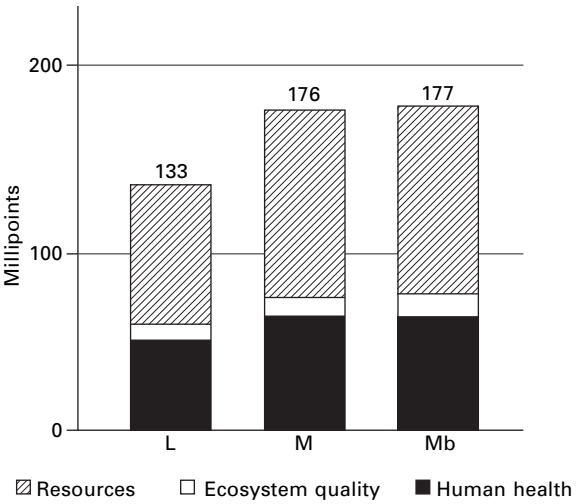
The process LCA of the more sophisticated fabric M (Fig. 4.45) shows four high impacts, which are originated by the desizing process, the two dyeing processes and the finishing process for dimensional stability, and three lower impacts, mainly produced by specific finishing and drying processes. The same categories are mainly affected as in fabric L. The level of the four higher impacts lies between 120 and 180 points, that of the lower impacts between 30 and 45 points. If calculated per meter finished, it becomes obvious that the production of M causes higher impacts in analogy with the greater number of processes. However, the impacts are not as high as expected since the batch is very long (see Fig. 4.46).

There is also the variation of equipment as shown in Fig. 4.47. A comparison of the two processes shows little difference. The conclusion for ecological product development is a reduction of processes, as can be achieved by a combination of pre-treatment and/or dyeing processes, if the required quality standards can be met. These LCA results would differ even more if all substances could be evaluated, since due to confidentiality not all substances of the printing and finishing processes were revealed and could be calculated in the LCA. The two different technologies do not produce large differences, but should be evaluated in combination with process reduction. Not rated, as generally in the LCA results, is the considerable amount of manual mechanical work with fabric L.

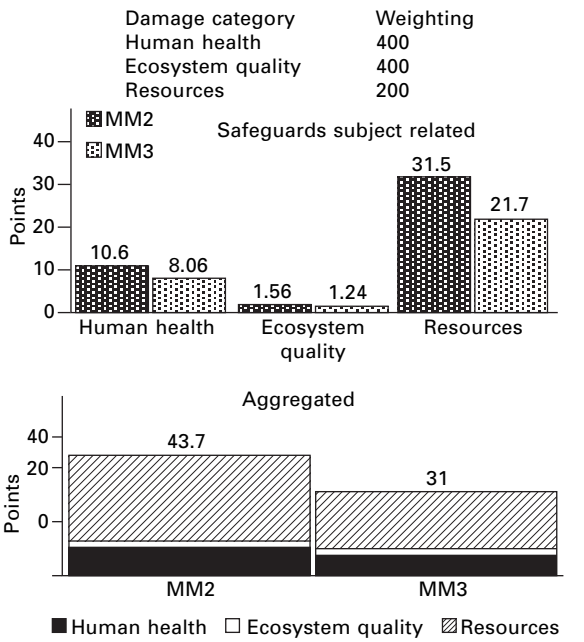


4.45 LCA results of the finishing processes for fabric M (case study D).

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4.46 Comparison of LCA results for fabric L and two technology variations of M per meter (case study E).



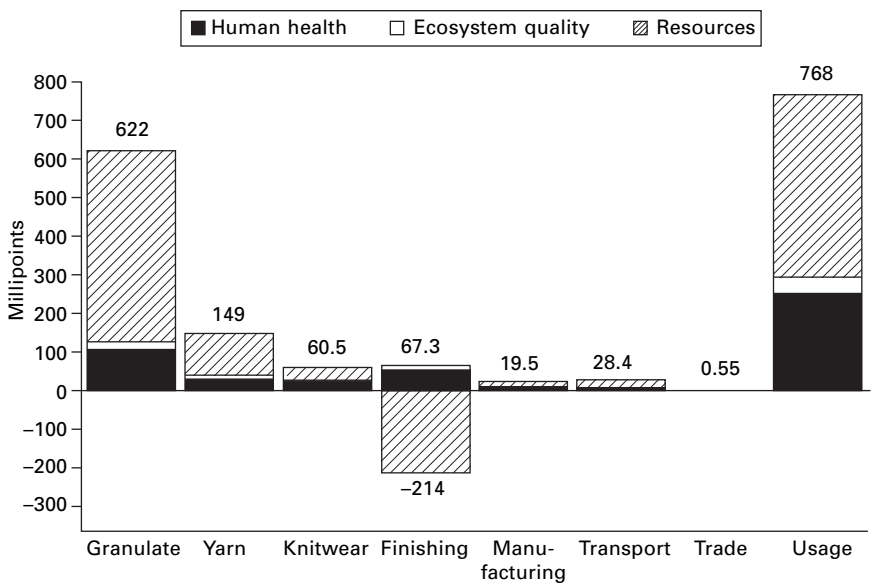
4.47 Detailed comparison of two pre-treatment technologies applied for fabric M (case study E) with method EcoIndicator 99 (subject related and aggregated). The weighting factors are given at the top. One point (Pt) relates to 10^{-3} average annual impact of a European consumer.

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4.5.4 Case study G: Part lifecycle PES T-shirt

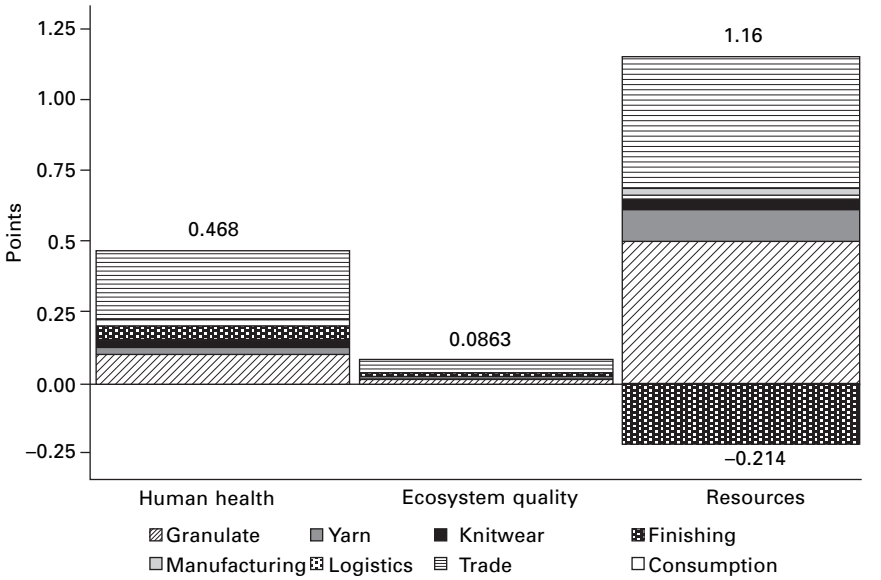
The results of this case study are company based for the individual steps fiber production, spinning, knitting, finishing, manufacturing and the use scenario. Consequently they do not represent an individual product, but the company's average impacts per output unit. Assessment of a life cycle was only a sub-part of case study G, because the aim was the comparison with recycling and remanufacturing scenarios. For this purpose the accuracy of this setup was sufficient (see Section 4.5.6). A special situation was found in the finishing company, where the prime energy source is fat from animal bones. This led to the surprisingly negative impact on this very general level. In the finishing inventory, product-specific chemicals were combined with average process technology for PES (Fig. 4.48). The PES knit requires a smaller number of processes in finishing compared to the cotton products in the studies D and E. There is no pre-treatment (removal of impurities and wax) and accordingly little finishing (addition of softener for removed waxes) applied. But energy consumption is higher due to PES-specific high-temperature dyeing.

Highest impacts are produced in the granulate production and in the use phase with resources being the most affected safeguard subject (EcoIndicator 99 H method). Figure 4.49 gives the aggregation of production steps, which



4.48 LCA results (single score, EcoIndicator 99) of a company-based life cycle of a PES T-shirt (case study G). The negative impact of the finishing processes is achieved by means of the alternative energy source (fat from animal bones).

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4.49 Aggregated LCA results for the production of the PES T-shirt (same system as for Fig. 4.48) in EcoIndicator 99.

contribute to the three safeguard subjects human health, ecosystem quality and resources (see Section 4.2.3).

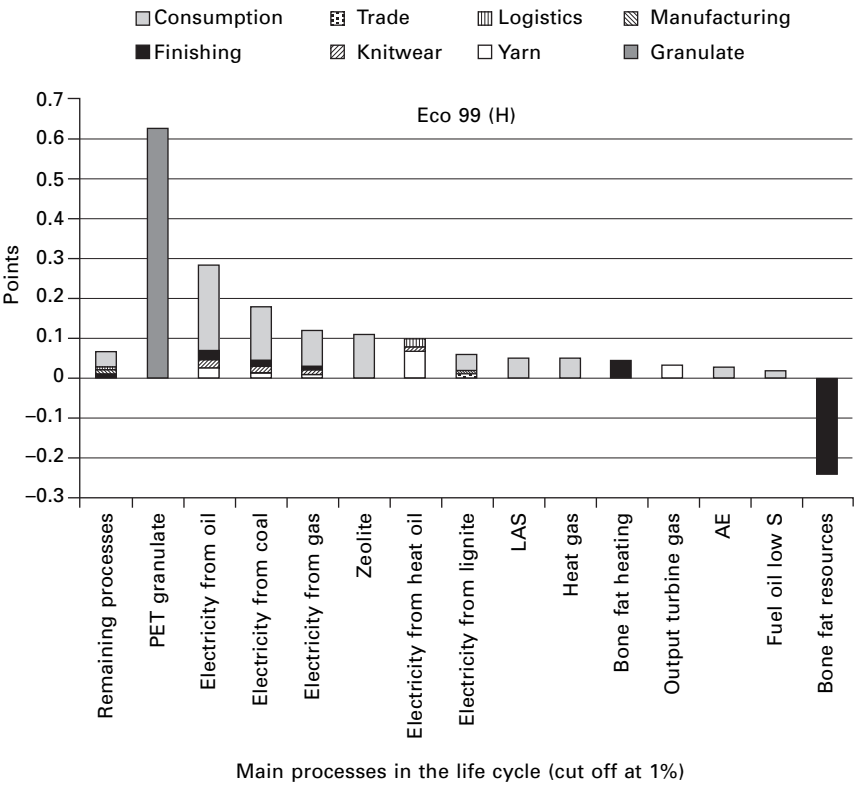
As shown in case study B, the spinning and knitting process of PES fibers causes lower impacts than with cotton and other cellulose fibers. If conventional fossil energy was used as prime source, also PES finishing processes would cause a considerable impact.

The different contributions by the individual steps in the value-added chain are presented in Fig. 4.50, where only impacts <1% are not listed.

4.5.5 Case study F: Laundry services and private laundry

Most laundry services include a mix of dried, flat-ironed and formed-ironed laundry, while private (domestic) laundry processes are based on tumble-dried and ironed laundry (the most common scenario). Accordingly, professional drying processes are carried out with tumble-drying, mangling and tunnel finishing, whereas private drying processes rely on tumble-drying and ironing. Comparison of professional laundry services with the private household laundry scenario indicates a better ranking of the professional care type, for an average 1 kg laundry (see Fig. 4.51, upper part). This is mainly because of the specific laundry mix in textile services with considerably more non-ironed laundry in the textile services. Although impact values are on a comparable level, the safeguard subjects are different: the professional washing process

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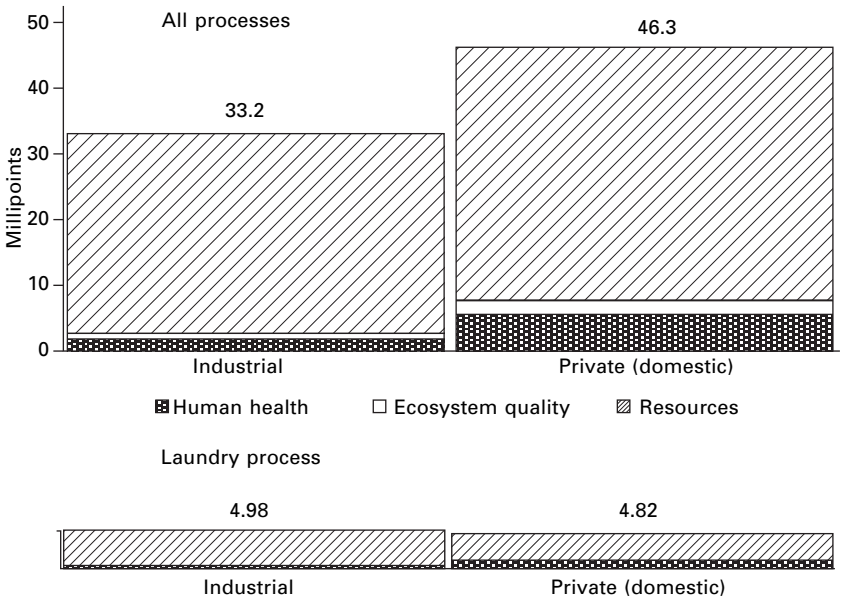


4.50 Detailed LCA results of processes for a PES T-shirt life cycle, including consumption.

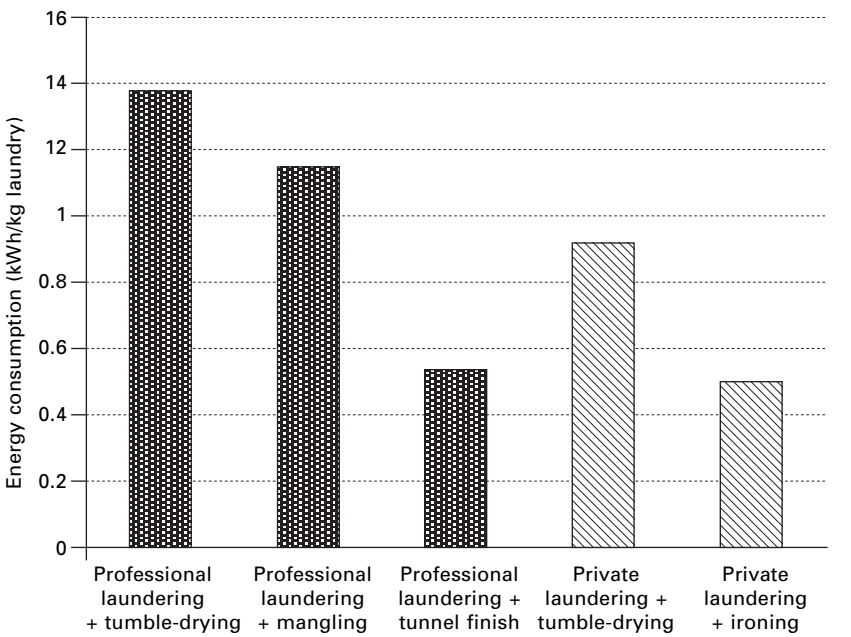
is mainly based on steam treatment, based on fossil fuel, thus mainly on resources, while household washing processes are carried out with electricity which results in impacts on all three safeguard subjects.

However, the results for professional washing processes might be too low because some data on chemicals could not be inventoried (see Section 6.2). If we consider only the inventory of energy consumption calculated in kWh (Fig. 4.52), it becomes obvious that the two household laundry processes have a lower consumption than the three from textile services. Conversely, water consumption and washing agent consumption per functional unit are lower for textile services (Fig. 4.53). The lower water consumption is achieved by the different technologies: reuse of water in the professional equipment with 12 processing chambers versus ejection and dumping of

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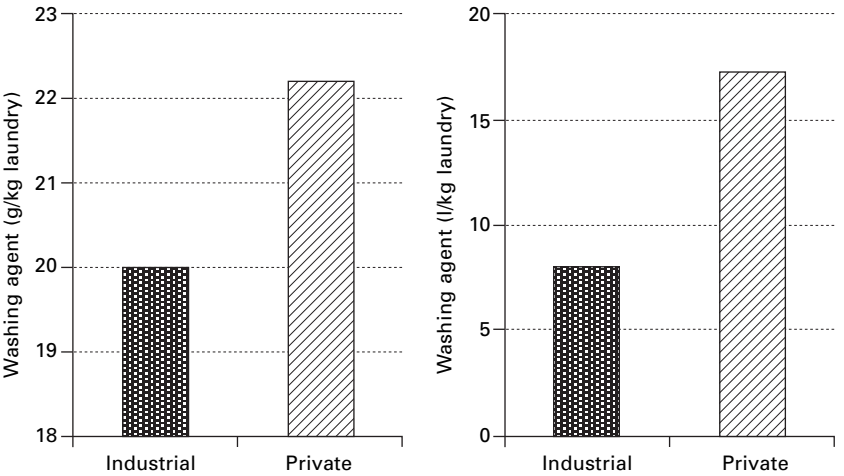


4.51 LCA results for professional and private laundry (including washing) and washing processes (case study F).



4.52 Energy consumption of laundry processes (case study F) (source: Pulli 1997, Affolter and Steiner 2002).

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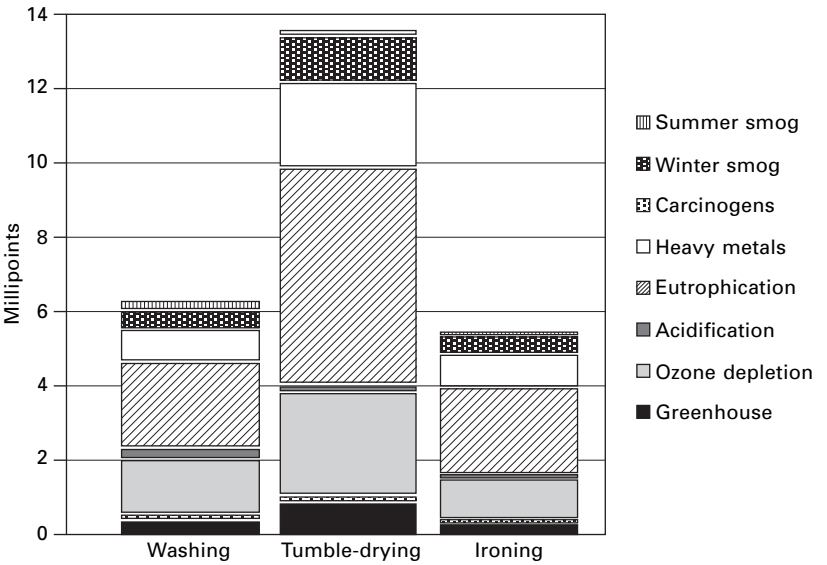
4.53 Inventory of washing agent and water consumption of professional and private laundry (case study F) (source: Pulli 1997, Tobler *et al.*, 2002).

each rinsing water in the household machinery. This finding is surprising and shows that the machinery for professional laundry is optimized only in water consumption but not in energy consumption. These results are in accordance with a survey on textile machinery, giving no evidence on development trends towards lower energy consumption by the end of the 1990s. This trend may have changed since then, but as we have to count on about 10 years for the development of new technology, a change would not have been expected before 2010. The option with a setup of heat recovery would probably be more economic than an exchange of machinery. The available inventory of washing agent, as provided by the company, did not give sufficient information on the associated impacts, because substances can be more or less harmful. Professional washing agents may be more effective and harmful, but they are given in an economical dosage. Often household washing agent is given in a surplus dosage, because the water quality (calcium content of the water) is not known, or because people still believe more washing agent produces cleaner laundry.

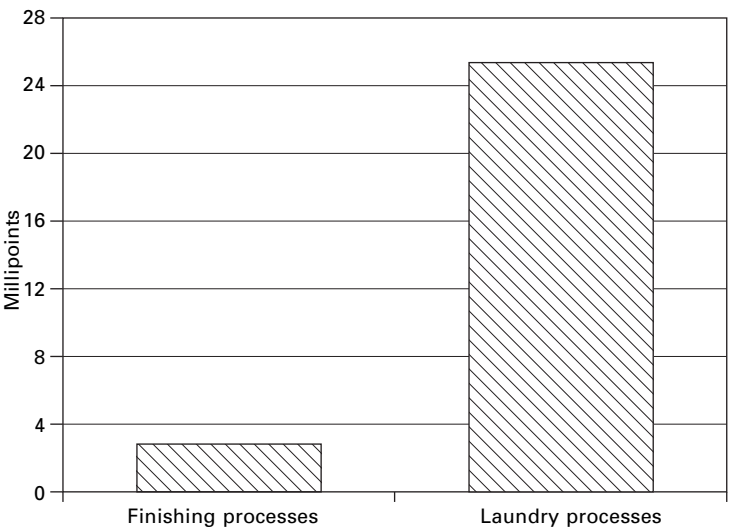
The results for private households (Fig. 4.54 from Pulli 1997) are specified for tumbled-dried and ironed laundry, which apparently is very rare in practice. Most laundry is (a) tumble-dried, (b) ironed after drying on the clothes line, or (c) simply dried on the clothes line (Affolter and Steiner 2002). Additionally, the results for private textile care may vary due to the different washing behavior of consumers (see Chapter 2 and Section 4.6).

An interesting comparison between the washing processes of the use

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4.54 Environmental impacts in consumption (EcoIndicator 95) (source: Pulli 1997).



4.55 Comparison of finishing and laundry processes on a basis of 48 laundry cycles (EcoIndicator 95) (source: Pulli 1997).

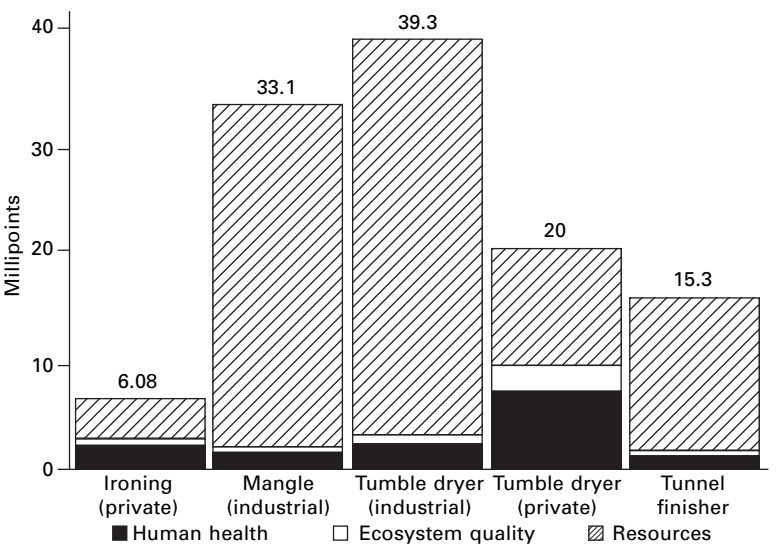
phase and the finishing processes has been made by Pulli (1997) (see Fig. 4.55), who showed the relation of 48 washing cycles of a T-shirt, equal to 26,000 micropoints, to finishing, equal to 3000 micropoints. Washing cycles included again a full program with tumble-drying and ironing.

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The particular mix of the professional laundry, with a large amount (in kg) of tumble-dried linens from hospitals, is essential for the better ranking of the professional service (see Fig. 4.52). If the comparison is made between the specific drying processes for formed laundry (as calculated in the results for the private household), the impacts for the private household are lower (Fig. 4.56). The comparable processes are private ironing to mangle or tunnel finisher, and professional to private tumble-dryer. This result is somewhat surprising and requires additional analysis.

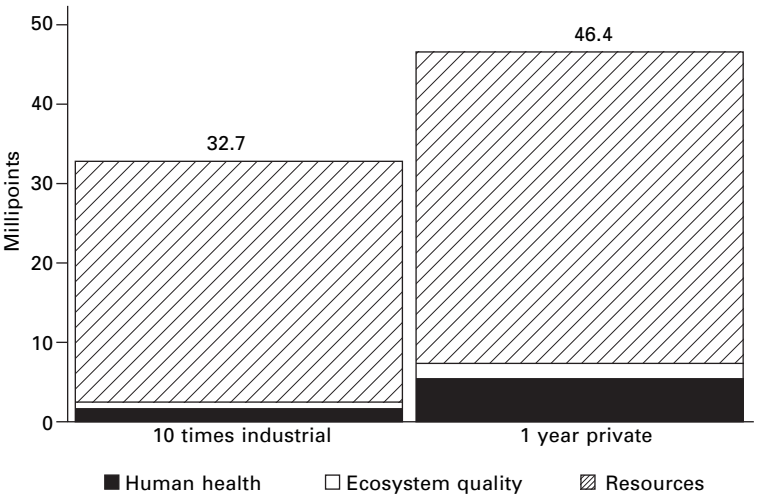
Future trends were developed for decreased household activities, because working people wish to spend less time on them. They also might make use of a textile service for their private laundry in a city. The purpose was to compare environmental impacts. In a future scenario the impacts of a central laundry service for private households were investigated and compared to the average impact by private households, based on Affolter and Steiner (2002). The scenario included professional laundry and a laundry collection and distribution system in a town of 500,000 inhabitants. As Fig. 4.57 shows, such a system seems to be preferable if based on the inventories of Pulli (1997) and Zbinden (2005).

Whether people would be willing to leave such a private affair to public areas is a matter of discussion particularly considering classified data in contracts and bills with consumers.



4.56 Comparison of drying processes in professional and private laundering of case study F (EcoIndicator 99, aggregated).

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4.57 Scenarios for professional and private laundering including transportation (case study F).

4.5.6 Case studies G and H: Recycling/reuse

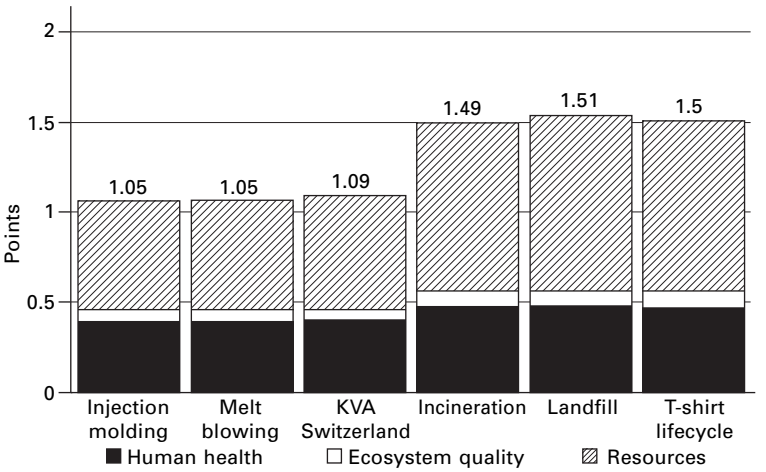
Man-made fibers like PES and PA can technically be fully recycled, even if such options are not practiced nowadays. The reasons may be found in the mixed applications of fibers and the existing logistics for recycling.

Polyester recycling

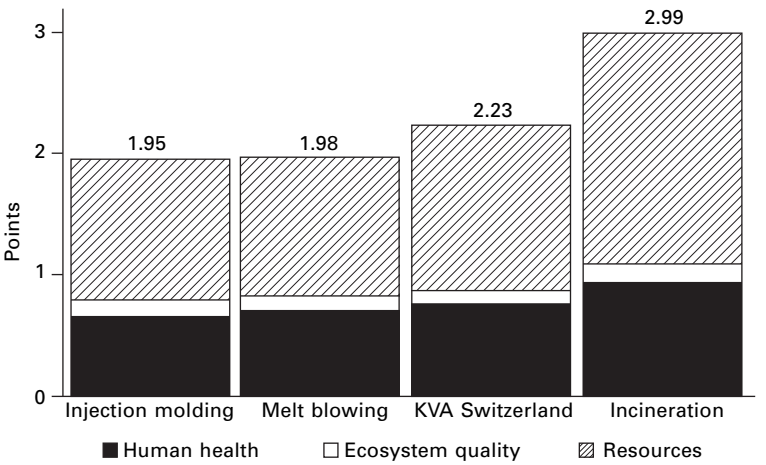
Nevertheless, under the pressure of an oncoming EU restriction for apparel recycling, such options for recycling have been evaluated. The initial situation in case study G was for pure PES clothes, such as T-shirts, sweatshirts, trousers, etc., with all accessories (zips, buttons and press buttons) made of pure PES. The comparison of the product life cycle from raw material to point of sale (from 'cradle to gate) was made with four different options: recycling (by means of melt spinning), reuse (by means of injection molding), Swiss household waste treatment (KVA, with heat recovery), and incineration with landfill. The incineration and landfill options are almost equal to the production life cycle, as Fig. 4.58 shows.

Recycling, reuse and KVA incineration equally give a 30% better ranking. Assuming the same options for a second life cycle, thus after the T-shirt has been reproduced, based on material from the first life cycle, the results for the recycling and reuse options are equally best, KVA is only slightly worse (12%), and incineration is more than 50% worse (see Fig. 4.59).

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4.58 LCA results as a single-score graph: T-shirt life cycle with recycling options injection molding, melt blowing, KVA Switzerland, incineration (partial thermal recycling), landfill, and reuse (case study G).

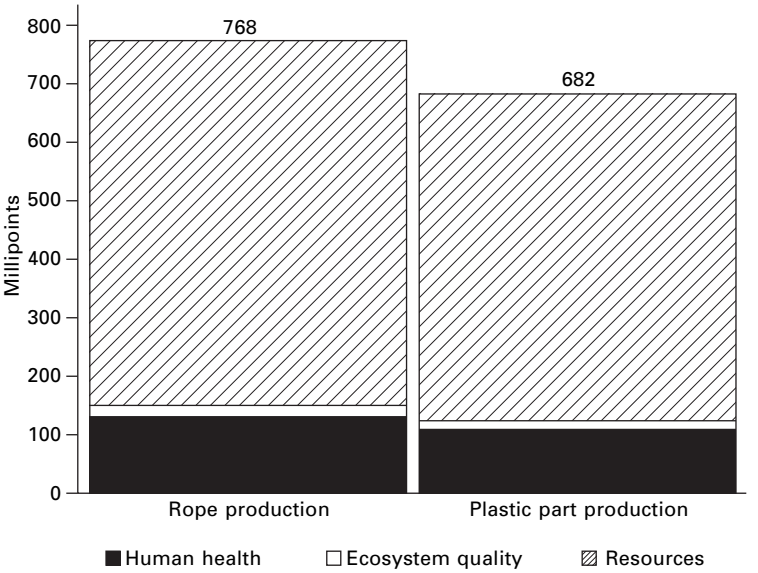


4.59 LCA results as a single-score graph for two T-shirt life cycles with recycling options injection molding, melt blowing, KVA Switzerland (partial thermal recycling), and incineration (case study G).

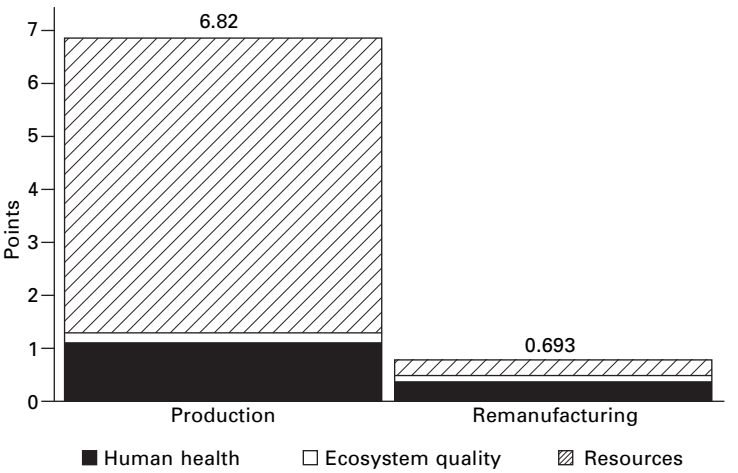
Polyamide

Case study H on recycling of polyamide gives results with only limited significance (see Sections 4.4 and 4.6) for the selected nylon products and their recycling options. Figure 4.60 indicates the LCA values for production

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4.60 LCA results for rope production and plastic part production from PA 6 (case study H).



4.61 Plastic part: production and remanufacturing (case study H).

of a PA 6 rope (fiber application) and the production of an injection molded plastic part (plastic application). The impacts of the production of this plastic part and its remanufacturing equivalent, produced from climbing rope material, are presented in Fig. 4.61.

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4.6 Life cycle assessment (LCA) sensitivity analysis

In the first part of this section, textile process LCAs are discussed from the viewpoint of significance for product LCA and whether the case studies represent typical or ideal cases. The second part investigates the consequences of the setup of the system modeling and the functional unit, with reference to the product and the processes. In the third part the data reliability is analyzed, and the fourth part focuses on methodological issues of life cycle assessment. In a final overview LCA in textiles are validated.

4.6.1 Textile processes and life cycles

LCA is defined to include all impacts from raw material to disposal ('cradle to grave'), or at least from raw material to the point of sale ('cradle to gate'), since the behavior of individual consumers, in the particular case of textiles, is neither known nor traceable. Process LCAs, carried out within one company of the textile's life cycle, may use individual functional units according to the defined goal. We can distinguish between process LCA (a product's life cycle within the company) and company LCA, including all inputs and outputs of the company. In the first case we get a very precise inventory of a product, but supply processes like energy management, or end of pipe processes like emission, effluent and waste treatment, often cannot be allocated to the individual product. Table 4.13 gives an overview of significant parameter for a textile life cycle.

The results from the individual process LCA have only limited importance for the whole life cycle of textiles in general, since there are many diverging parameters, particularly in quality aspects. Even the same fabric quality (see Chapter 3) produced with different process technology or on different equipment or with different formulas will result in different impacts. But especially this fact makes process LCA so valuable for product development of a company. Dahllöff (2002) also found different results for textiles, but worked also with literature data, whereby products and processes were not specified.

For the presented case studies this means that we may not conclude that every knitted fabric is more environmentally friendly than every woven product, although we can show a tendency towards that statement (see Fig. 4.35). For comparison, the functional unit of end products has to be chosen identically. This means comparing fabrics with a defined consumer use, like T-shirts or blouses of a defined quality given by abrasion tests, pilling tests, color fastness tests, etc. The producer has to evaluate the technology and the formulas he applies also in terms of costs and legal compliance. Regarding the variety of the production processes, it is obvious that LCA can only be elaborated for representative products and processes of a company, due to economic considerations.

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Table 4.13 Comparison of parameters set in process LCA and parameters (mainly supply processes) set at company level

Step in life cycle	Process LCA	Company LCA[1]	Remarks
Agriculture	Specific machinery and soil requirements, site specific irrigation	Average practice, mix of crops	Strongly site and time specific Strong influence of farmer's knowledge High yield produces better results
Chemical fiber production	Energy efficiency, often patent on processing	Mix of products and qualities	Producers are monopolists Individual data (energy management) mainly confidential
Transports	Specific vehicles, distances and volumes for individual fiber properties or products	Mix of fibers or products	Procurement often changes
Spinning	Specific technology, product quality	Energy prime source and management (air conditioning), waste management	Strong influence of process technology and energy management, yarn fineness
Weaving	Specific technology, fabric types, sizing agent	Energy management, sizing management	Waste management dependent on process supply calculation
Knitting	Specific technology, fabric types	Air conditioning	Waste management
Finishing	Quality parameters: color fastness, dimensional stability; required comfort parameters and special properties	Changing mix of products and formulas, energy prime source and management, water management, effluent and emission treatment	Options for water and energy efficiency, effluent and emission treatment are highly product and product mix specific
Manufacturing	Energy consumption for sewing	Process energy (and heating energy), waste management	Energy consumption and waste management are highly related to product requirements
Trade			Processes are not product specific
Use phase	Temperature, laundry agent, dosage, ironing	Frequency and efficiency of washing process, drying equipment, preference of fibers	Life time duration of a fabric (washing cycles) in relation to production

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Table 4.13 Continued

Step in life cycle	Process LCA	Company LCA[1]	Remarks
Recycling/ disposal	Reuse (second use phase), landfill, incineration	Heat recovery from incineration	Incineration processes are not product specific[2]

[1]In agriculture this is related to a farm, in the use phase to a private household.
[2]Incineration value can be calculated theoretically.

Agricultural systems like cotton growing are highly site specific and also depend on the farmer's strategies and his experience in good practices (Hauser 2000, Tobler 2002a). If farmers aim for high yields with low inputs of agrochemicals and tillage, in time they will produce fewer environmental impacts.

Struszczyk *et al*. (2002) and Urbanowski (2004) developed different inventory scenarios for alternative technologies with regenerated cellulose (viscose). Likewise is the growing of hemp (Tobler and Leupin 2004, Heller and Strybe, 2004), where different regimes are applied according to the energy resources and environmental legislation. Thus practice and technology strongly influence the impact by the raw material.

Administration in companies makes only small contributions to the impacts and is therefore negligible, as results in a spinning/weaving company (Luchsinger 2002) show (see Fig. 4.37). The energy calculation (kWh) per functional unit (FU), based on company allocation, may differ by a factor of 2 from process measurements.

The spinning and weaving processes can be elaborated with higher significance due to limited varieties in process technology, whereas finishing processes are designed to be unique for each company. However, transports of fiber material, depending on the origin of the fibers, contribute to the complexity of the spinning mill system.

A general simplification in finishing processes is often made by including the average effluent load instead of process-based values. Process-related measurements are generally not available in finishing companies, especially if upstream water recycling and neutralization of effluents is applied. A similar situation occurs in airborne emissions. Heat recovery from effluents and emissions represents another complex allocation problem. LCA practitioners of COST Action 628 (Nieminen *et al*. 2007) agreed on the following simplifying allocation: to include average effluent and emission loads per output unit. LCA results in finishing highly depend on water and energy management of the company as well as on the prime source for energy (Tobler 2001c). Depending on the national energy sources for their electricity production, coal and other fossil resources, hydro and nuclear power are applied in a country-specific

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mix. The steam production is coal, oil, gas or propane based, depending on the availability. Consequently, comparable processes can lead to different impact levels, depending on the production site and/or the country.

Companies are often very innovative in energy management. Case study B (Bernasconi and Ackermann 2005) found production of electricity as a by-product from steam production based on coal, while case study G (Mathieu 2003) reports fat from animal bones, a CO_2-neutral energy resource in a finishing company. The differences caused by the prime source can be as great as those caused by different process technologies, for example airjet weaving versus multiphase weaving technology M 8300 by Sulzer (Luchsinger 2002). Depending on national legislations or voluntary investments, some companies maintain a waste water treatment on site, others eject to a canalization system, and some eject to surface water (so called lagunas). Another difference of impacts is caused by the water supply for processing in site. This may be surface sweet water, ground water (De Vreese 2004) or pre-treated water from the sea. From such differences new questions arise about scale and scope of the studies as well as on system modeling. They represent the main reasons why a scientifically correct comparison of company environmental performance may not be achieved. Appropriate measures can only be taken based on individual impact assessments, as shown for developing countries by Edelmann Colmant (1999) and Ries (2000).

Regarding a fabric's life cycle, the environmental impacts in the use phase are much higher than in finishing, as Pulli (1997) showed. For easier access to results, simplified life cycle methods should be developed, suited for communication along the value-added chain and particularly towards the consumer (Nieminen *et al*. 2007).

In every manufacturing company textile parts are assembled to apparel, mainly by means of sewing technology. Even if manufacturing quality standards diversify strongly, the environmental impacts are based on electrically driven sewing machinery of any kind. Waste production, as a result of cutting the parts from the fabric, is highly dependent on the fabric pattern and the apparel style. The latter is influenced by quality requirements and fashion aspects, which often change from season to season.

The environmental impacts of the textile and apparel trade correlate with the distances in the supply chain. These are set by product development and sourcing as well as by the chosen marketing channel. In a well-organized procurement the favored means of transportation are bulky container ships and local trucks. Railroads are usually considered to be too inflexible. But occasionally also air freight is chosen, particularly in situations with high (time) competition. At the point of sale the situation is similar for all merchandise. Since the equipment remains the same over a certain period, the inventory can be defined as per m^2 of merchandise with respect to heating and illumination energy (see also Chapter 5).

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The use phase determines the greatest environmental impacts, based on the cultural orientation and preferences of the different nations, but also on the available technologies. The consumer's choices of apparel care properties, the energy consumption of the machinery and the choice of laundry agent determine prominent impacts. The frequency of washing (cycles per lifetime) is determined by demographic parameters such as society, race,[4] education, age and gender.

Disposal and recycling processes are part of a logistical waste management system, which is individually developed in every nation, whereby different textile fractions are generated.

4.6.2 Sensitivity analysis

The sensitivity analysis considers all parameters influencing the results of an LCA. The main aspects are set by system modeling, data quality and methodological aspect (see Section 4.6.3).

A first, very general statement is that system modeling in agriculture is completely different from system modeling on the level of companies or private households. Consequently we must expect also different functional units in these different groups. In the following comments each case study will be discussed, whether it represents a typical situation, and what the consequences of the selected functional unit, the completeness and reliability of data are.

For all case studies (A–H), data quality of inventories can be defined on two levels: the completeness and the accuracy of the values. The completeness is given if all data within the system border are collected as measurement, calculation (based on chemical and physical laws) or estimation. Measurements are considered as most accurate, estimation as least accurate.

Case study A: Cotton growing

The chosen growing season of 2001, with drought and diseases, was one of the 'worst years since the Civil War'. In certain regions up to 60–70% of the crop was lost because of a hail storm on 31 May. Therefore the results may not be representative in quantitative data (water consumption and yield). Since costs are correlated with yield (see Section 4.7), which again is dependent on the water supply, the consequences for the growing regimes become strikingly clear: in a dry season, dryland cotton becomes very expensive due to yield losses. Farmer W, situated 60 miles north of farmer B, might have

[4]Association with race is based on genetic determinations: Asian people generally produce less sweat than white people, and dark people generally produce higher amounts of sweat with different components.

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had the benefit of more rainfall (see Table 4.1). However, farmer B applied about double the amount of irrigation water per hectare and still had a very small yield. Therefore the small yields of 'BFurrow' and 'BLEPA' cannot be explained by a lack of water.

As shown for other agricultural systems (Gaillard 2000, Rossier and Gaillard, 2004, Schaller and Chervet 2006) environmental impacts highly depend on the practices of individual farmers, particularly in tillage. Nevertheless improvements in specific growing regimes can be achieved by the application of different pesticides. Besides this ecological rating, costs and yield have to be considered. The great impacts of the regimes 'BDryland', 'BFurrow' and 'BLEPA' are mainly caused by very small yields. All scenarios showed a great impact caused by the application of pesticides, so that the small yields cannot be related to a lack of pesticide input. If yields can be improved by altering management practices, without increasing pesticide application, impacts per kg cotton will decline and profit of farmers will increase. Nemecek *et al*. (2005) show similar results for selected scenarios in Switzerland. Taube (2006) reports surprising inventory results considering impacts of intense corn and grass production systems: the energy and nitrogen input efficiency is in favor of the intense corn production, maybe due to a specific and not typical season. However, the correlation to an 'unusual season' is not proven as in our case study A, because of the lack of comparable data.

All LCA calculations with the CML 92 method proved the great impacts of pesticides. It is known that other methods have a slightly different weighting of impacts. This fact requires further analysis and calculations to provide a deeper insight into impact assessment. A common basis is represented by the 'process tree' as proposed by Boura (2001a).

Cotton is grown in so many regions of the world with such different climates and soil conditions that this study does not represent a 'typical' case, if such a term even exists. It can, however, with some variations in water and pest management, be taken as a typical case in the USA, comparable perhaps with Australia, where cotton also is grown with high machinery support. Variations considering input of pesticides and water management within the USA were found by Spaar (1997) in a comparative study between California and Texas. But even if the inventories of cotton growing are restricted to the Texas High Plains, they cannot be considered as typical for the region because of the special weather conditions of the year of data collection. Effectively, all inventories also from different growing areas with different climate and weather conditions will vary over years. The functional units in agriculture are generally a square measure or weight, with the reason for the importance of yield achieved in the area as cited by Boura (2001b). Yield figures can also be taken for the evaluation of an average case. It is up to the judgment of the individual farmer whether to change inputs on the field when he gets aware of possibly declining yields. The data collection for a

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semi-desert climate is quite accurate with detailed, chronically structured inputs and outputs. It therefore represents reliable data for the specific case. The only open input was local variation in rainfall, which was not reported on site but taken from official measurements. The inventory did not include production of agrochemicals, although this would be an interesting aspect, as shown in Fig. 4.26, because impacts in production may or may not exceed impacts in application, based on application type (machinery and dosage) and direct impact by the chemical content.

In earlier studies (Eilrich 1991) the focus was more on human health aspects. Jolliet (1992) indicated specific requirements in methodology for agricultural systems. Gaillard *et al.* (1997) elaborated the first inventories for LCA of Swiss agriculture and presented the results in 2006, gained with specific software. New results on the fate of pesticides were elaborated by Charles and Jolliet (2003).

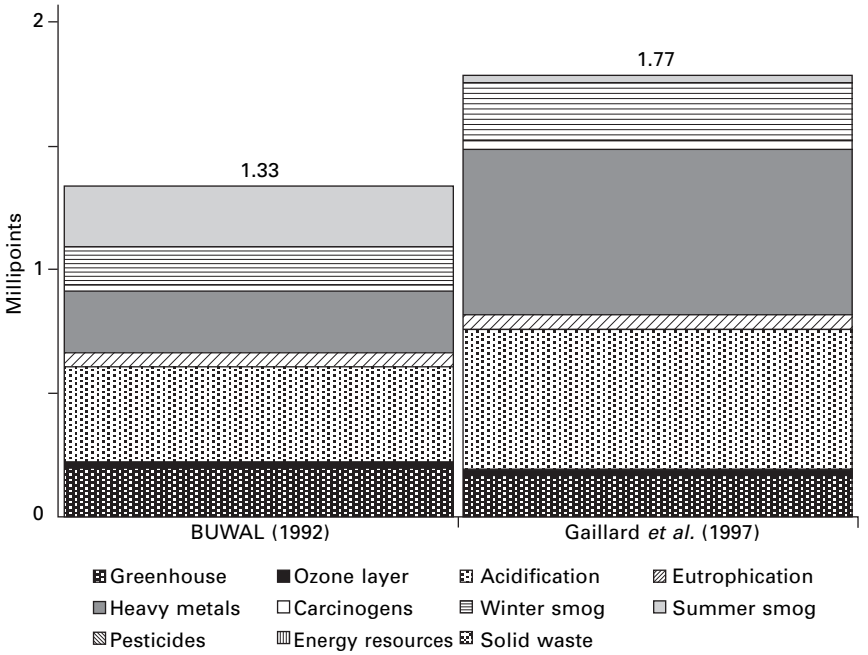
Case studies B and C: Spinning and weaving

Both fabrics can be taken as typical, because they are produced in considerable quantities and are made of cotton and PES, the most consumed fibers. Also the origins of the fibers are typical: in case study B cotton came from the USA (as in our case study A) and man-made fibers from a European company. Case study C gives a typical mix of sources (see Figs 4.15 and Table 4.9). The spinning mills in cotton areas source mainly in their own country. The data on polyester yarn production were taken from literature for this study, whereby the two data sources produced significant differences. The impacts of the newer data source produced a 30% higher impact, even evident on the level of the fabric, where spinning and weaving were included (see Fig. 4.62).

The highest impact in cotton growing (according to the SimaPro literature database) is caused by pesticides (77%) with EcoIndicator 95. This has been generally confirmed in study A, but the impact level varies within a factor of 200 with the CML method! There are considerable differences also between EcoIndicators 95 and 99. Thus, the results on raw material are based on an uncertain database as will be shown in the methodological discussion (Fig. 4.63).

The functional unit of spinning/weaving and spinning/knitting was taken as 1 m^2, including all waste calculations from fiber to fabric. In both studies the inventory was complete, except for the sizing formula the company did not wish to disclose (for sizing agents see Chapter 3). Dittrich-Krämer (1999) showed that industry has carried out LCA on different sizing agents, but her system is limited in scale and scope. However, the effect on the final result in weaving is marginal, because only small quantities of the sizing agent have to be disposed of. The main effect is achieved in finishing,

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4.62 Sensitivity of two different data sources for PES production: left, BUWAL 1992; right, Gaillard *et al.*, 1997 (case study C).

Table 4.14 Comparison of process and company-based waste fractions in spinning and weaving

Waste type	Process waste	Company waste (kg/FU)	Allocation (kg/a)	Factor (kg/FU)
Carding waste	7.08E-03	74,200	1.63E-03	4.4
Combers	8.13E-03	222,992	7.56E-03	1.1
Yarn waste	4.09E-03	82,372	1.8E-03	2.3
Fabric waste	1.08E-02	114,165	2.94E-03	3.7
Total	5.09E-02	633,750	1.06E-02	5.6

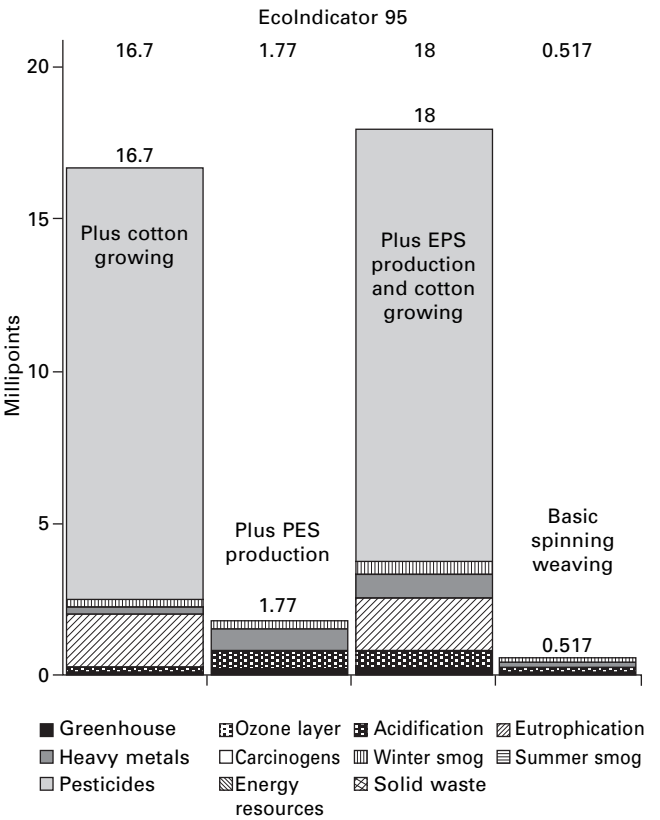
where the substance has to be washed out in pre-treatment. This process is included in case studies D and E. Data on energy were available based on measurements, except for nylon production (B), where it had to be calculated from a production model. A verification in C shows the differences of the individual measurement compared to company allocation that may occur (Table 4.14).

In study C also the administration and the infrastructure processes are included, but they are of minor relevance (Fig. 4.37). Popescu (2004) elaborated a process-based inventory for a wool system and defined the infrastructure processes as technical supports, whereby her measured influence is higher

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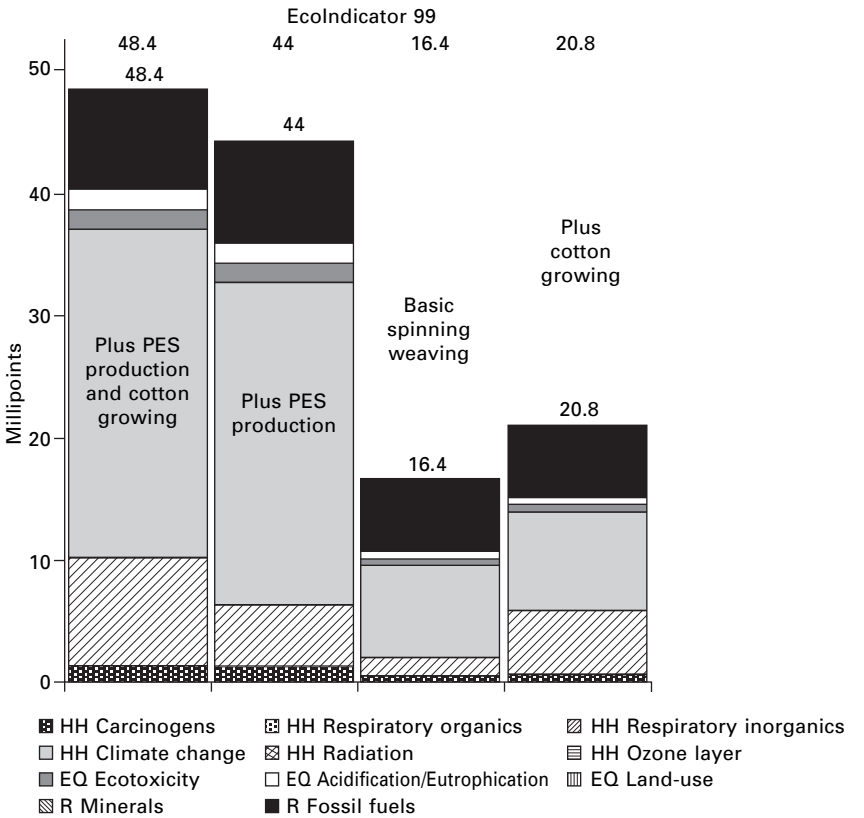
than in our case study. A major influence occurs through the prime energy source and the national energy mix. In our studies we applied a European mix, even if some national energy mixes would have allowed better results. As a result of buying and selling energy throughout Europe, we consider this the appropriate procedure. However, if a company produces its own energy supply we rely on this (Fig. 4.36).

The results of the two spinning/weaving processes clearly show the high influence of the products and its process technology (Figs 4.32 and 4.33). However, the results cannot be compared without considering the required quality of the individual fabric: although OE spinning of a selected fineness is superior to ring spinning, this cannot be generalized, since very fine yarns cannot be produced on the rotor spinning system, or because a soft hand is required. On the other hand, the choice of raw material (cotton or man-made fibers like PA or PES) highly depends on fashion and consumer preferences. Different technical specifications like water uptake, water retention and washing properties are not identical for the two T-shirt types (B). Also quality



4.63 Sensitivity of methods: EcoIndicator 95 and 99 (case study C).

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4.63 Continued

differences as shown in Fischer *et al*. (2001) produce different impacts, which cannot be directly related to products, technology or setup of the machinery. Therefore LCA results may be applied in product development only by giving a precise definition, namely of a desired quality and process technology.

Case studies D and E: Finishing

In both finishing studies D and E the impacts have been assessed on the level of a finishing company, whereby energy was traced back to its resources and chemicals were not. Such system borders might be considered unequal. Tracing back all chemicals applied is very time consuming and requires revealing of inventory data by the chemical industry. Many companies fear a disclosure of LCI data, although origins of impacts can only be seen on the process level and not on the product level. Binkley (2002) found similar

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gaps in data information for textiles in the UK. For supply and use of energy, detailed data on the individual situation were available in both studies. In both cases a typical batch length in production was chosen as the functional unit, because the length can vary according to the product type. Batch lengths for fashion products have become shorter and force European companies nowadays to work with not ideal production conditions considering ecology and economy, because the tanks of the finishing machinery are constructed for a given (mainly greater) production volume. Consequently water and energy consumption per m^2 become higher.

In company A of case study D, the collection of data on energy consumption failed due to the lack of sensors for measurements on the individual machinery. According to the requirements for allocation of impacts (ISO 14043), for example the heating temperature for a bath, already used for another product line, has to be split in the relative fraction. For a complete inventory, the energy consumption of the individual processes is calculated, based on their radiation, convection and conduction of energy (Zwicker 1997). By calculating the heating energy for bath, fabric and machinery (only for non-continual processes) and the compensation at the machinery's surface, we obtained a value not as accurate as that measured but better than an estimation.

The differences in the prime energy source for steam production (oil or gas in study D), coal (study E, where it was also used for electricity production) or alternative energy (animal bones in study G) are very large. These systems are unique to each company and data can be analyzed only on a company level. The same structural difficulty can be stated for heat recovery systems, where the temperature difference of water and airflows is applied for heating operations.

A favorable aspect of CO_2 reduction is achieved by neutralization of baths with airborne emission from selected process emissions (BFE, BAFU 2005). In case study E some data on the efficiency of energy production rely on information from the technical department of the company. Such information generally has to be regarded as less reliable than one's own measurements.

In study E some data on chemical content were not disclosed and therefore the inventory is not complete on the 'chemical part', which causes unknown differences in the results. Even if the content of textile chemicals is known, the assessment is not simple. Pulli (1997) investigated persistence and accumulation of some chemical groups in finishing and laundry, for which Beck (1999) developed a specific system for evaluation of chemical groups. However, the individual chemicals cannot be assessed by LCA with these models. Effluent outputs were calculated as transfer coefficients in study D, but were measured as summary parameters in study E. The results gained with the inventory in study E may be representative for a Central European

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company, but are different in locations with different or no obligations for water treatment on the company and/or community level.

Some processes like rinsing and drying are only applied in combination with other specific processes or for specific products, and are creating more environmental impacts than other products. For such reasons Nieminen (1997) restricted her studies in Finland to the effluent parameters. However, even such information is not always disclosed by companies, as shown by Binkley (2001) for dyestuffs in the United Kingdom. In other countries like Romania (Dumitrescu 2003) such information is required by authorities on a monthly basis.

The application of either exhaust or pad process technology leads to different inventories, considering also transfer coefficients of substances. Even if the pad system causes lower impacts, this result cannot be used as a general recommendation for this system, because it is not suited for all textile products (see Rouette 2003).

By applying the same formula for different batch sizes of finished fabric, the inventory differs considerably in the use of energy and some chemicals. Data on production of laundry contents are available (Dall' Acqua *et al.* 1999) if the specific products are declared. Minor contents may cause relatively higher impacts than large ones. In study E this effect must be assumed when comparing the sophisticated product to an average product (see Fig. 4.47). The LCA study of Kazakeviciute (2004) of a camouflage product certainly shows different impacts due to the specifications, but also because of the prime energy source.

Case study F: Laundry

The laundry inventory was collected in an ISO 14000 certified company and can be taken as typical in the mix of rented laundry and customer services. Processes for disinfected laundry, as used in hospitals for highly infected laundry and for epidemic cases, are not included in the system, because they are carried out in a different site. As a functional unit 1 kg dry laundry was taken. The inventory was complete on the machinery applied and the support processes, but some specific data on chemicals were not revealed. Therefore the impacts may be calculated lower than in reality. The data for household laundry were taken from Affolter and Steiner (2002) and Pulli (1997).

For reliable results the study should be repeated with actual data and detailed laundry inventories, including washing temperature options, washing agent varieties (for which such results may be available in the industry) and drying options in private and professional processing. Grüttner (2004a) presented selected results for textile services, without revealing the database.

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Case studies G and H: Recycling

The concept of case study G for the PES T-shirt was based on a product life cycle, not on process LCA. In none of the companies of the value-added chain were process or product specific data available. Consequently the functional unit was set as 1 kg T-shirt, particularly since the yarn producer and the manufacturer calculated in weight. All company data had to be calculated on this functional unit with reference to the fabric weight. The inventory in spinning and knitting and manufacturing is mainly energy based and typical for the production type of company. Unlike in study C, production-specific data for PES spinning and granulate production were available at company level. (Granulate production refers to old process technology, given up in the mid-1990s in Europe.) Struszczyk *et al*. (2002) showed differences in the inventories for alternative technologies in processing cellulose pulp fibers on a laboratory scale, hence probably different from those on an industrial scale. We must also expect differences from company allocation to process energy consumption as presented in Section 4.6.1. Thereby the following rule can be applied: the finer yarns and knits are higher in energy consumption for a fabric of the same weight. A particular case was found in finishing, where the CO_2 neutral prime energy source produced a negative impact. Data on chemicals were communicated by the company and therefore may be less reliable than if they had been collected on site. Data on incineration scenarios were taken from Hellweg (2001) and data on injection molding and melt spinning were taken from literature. To summarize, this study covers a whole life cycle with different recycling options based on company average and specific data with different reliability.

For a comparison with other business, Oetiker (2001) analyzed environmental impacts and cost of recycling and incineration in Swiss KVA in the electronic waste sector. He found an ecological advantage of the recycling but an ecological disadvantage as long as resource prices are low enough. This discrepancy is not relevant in the European Union, because legislation (WEEE[5] and VREG[6]) makes recycling mandatory. A similar tendency might come up in the apparel case.

LCA results from case study H are certainly not representative of nylon production because (a) rope production is a very small fraction within PA fiber products, (b) the quality requirement, particularly the technical specifications, of the technical textile are different from the apparel application, and (c) the inventory is based on a calculation model,[7] representing an estimation rather

[5]Waste of Electric and Electronic Equipment.

[6]Verordung zur Rüchnahme von elektronischen und elektrischen Geräten (regulation on redemption of electronic equipment).

[7]Data from Swiss Customs.

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than precise values. The scope of the study was the inventory of annual material flows, which is precise for the year of data collection. Inventory data were only collected on a company basis. The LCA was more a by-product because the experimental part for the feasibility was the main topic of case study H. The functional unit was chosen according to the plastic application as 1 kg and not as weight per length (of the rope) as is standard for textile applications. Similar to this setup, Mebold (1996) worked with a calculation model for the inventory database in shoe production, but with average processing data (from the computer software). We can conclude that the scope of a study influences the accuracy of its results.

Another study on energy for recycling options for apparel made of cotton gives a good rating for all downcycled products (see Table 4.15). Cotton cannot be recycled to the original fiber, but can be processed to new products by processing to specific shred followed by pressing processes (for products like roofing board) or spinning processes (for new coarser yarns for a variety of products).

There is a general criticism concerning secondhand apparel being shipped to developing countries (Maechler *et al*. 2004) where it competes successfully with domestically produced apparel. Merchandising of secondhand apparel has become an important market in the African countries (Rivoli 2006). On the other hand, apparel from industrialized countries is often produced in better qualities and consequently has a longer lifetime. Eventually, developing countries might improve the quality of their domestically produced apparel given the right conditions provided by their governments.

Comparison with existing LCA of textiles

Examples of LCA in textiles are rare, and most are classified because they are based on specific company data. One of the earliest inventories was elaborated by Franklin Associates Ltd in 1993 but not published. Viscose production was analyzed as LCA (Fischer *et al*. 2001, Schmidtbauer 2000), when the Lenzing company had to increase its environmental performance, which it achieved successfully. Kalliala and Nousiainen (1999) published one of the first, but simplified LCA for cotton and cotton polyester fabrics. Kazakeviciute (2004) specified a printed camouflage fabric and Visileanu

Table 4.15 Energy consumption of production and recycling processes

	Energy for a new product (MJ/kg)	Energy for recycling	% of recycling
Apparel	254.8	4.36	1.7%
Cleaning towels	89.8	3.86	4.4%
Tear strips	57.1	10.36	18.1%
Roofing board	44	9.36	21.3%

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and Popescu (2004) collected inventory data in spinning and weaving for woolen fabrics, both certainly different from plain cotton fabrics. Chemicals, such as special dyestuffs, were investigated by Weidenhaupt in 1997 with CIBA, but not published. Dittrich-Krämer (1999) analyzed sizing systems with BASF. The software GABI holds data sources from textile companies which are not disclosed or specified. As these case studies represent individual cases, the publication of a database would decrease competitive advantage in product development for the companies.

4.6.3 LCA methodology

In this section some of the most prominent influences of the methodology in relation to the presented case studies will be discussed. All these results were elaborated between 1996 and 2005, thus in a period when the methodology changed constantly from a basic impact assessment model of CML to the actual methods CML baseline 2000 and others (see also Sections 4.2 and 4.3). The impact categories changed or were newly introduced or grouped, because of actual knowledge on substance flows, or they were combined with new calculation models in complex systems like agriculture. Social values, shaping the viewpoint of the actors, were introduced. A distinction between long-term and short-term effects leads to advanced calculation models (Huijbregts 2004), e.g. for metals. Different attempts have been developed by setting the time of emission or the damage effect or weighting future against current damages by discounting (Hellweg 2004). All this was developed in interaction with the developing ISO regulations 14043 ff. The presented case studies had to orient to the best available method at the time they were carried out: EcoIndicator 95 and EcoIndicator 99. A strict interpretation of the ISO standards would consider these methods as aggregated methods. However, the graph with all impact categories seems to provide sufficient information on impacts. LCA calculations were made with subsequent versions of the software SimaPro, the most widely used computer tool. In this version the newest methods were introduced and the literature database was constantly updated and enlarged.

Through this steady change in methodology, consistency of the results became impossible to maintrain. Case study C, carried out in 2000, had to face the fact that the same inventory gave not only slightly but completely different results if calculated with the EcoIndicator 95 and EcoIndicator 99 methods (see Fig. 4.63).

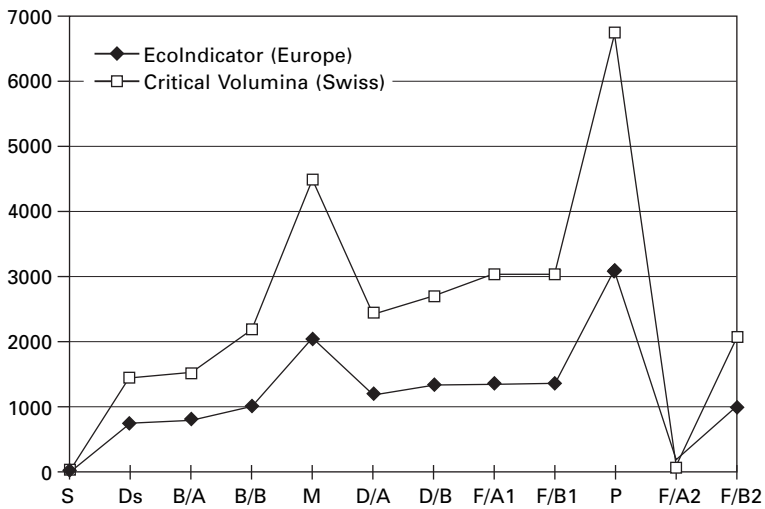
Not only did the values change, but also the impact of cotton growing, considerably higher than that of polyester production in EcoIndicator 95, changed to be even a little lower than for polyester production with EcoIndicator 99. Whether the differences occurred due to an updated database or because of a new calculation model is hard to explain to the practitioner. A Swiss initiative collects a common database, the EcoInvent, in SPOLD format.[8]

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Brent and Huitkamp (2003) present similar activities in a case study from South Africa, and in Thailand a database on energy is elaborated[9] as in many other countries worldwide.

Case study D (carried out in 1997) faced the problem at an earlier stage in the comparison of the BUWAL method with Ecoindicator 95 (see Fig. 4.64). Further validation of data is relevance and sensitivity[10]: LCI (life cycle inventory) data values are evaluated as slight changes will cause considerable changes in an impact category's value. Figure 4.64 gives the sensitivity analysis for case study D.

However, comparison of all processes showed a comparable shape and did not change the ranking between the different processes. The sensitivity analysis also investigated the contribution to the individual impact categories of the two methods. Small changes in the inventories were tracked according to their contributions to the impact categories of three methods. The highlighted results, gained with the different mixes of gas and oil as prime energy sources, clearly indicate the high rating of oil compared to gas with BUWAL: a change from 100% oil to 60% oil and 40% gas resulted in a



Key: S = singeing; Ds = desizing; B/A = bleaching, company A; B/B = bleaching, company B; M = mercerising; D/A = dyeing, company A; D/B = dyeing, company B; F/A1 = finishing, company A, process 1; F/B1 = finishing, company B, process 1; P = printing; F/A2 = finishing, company A, process 2; F/B2 = finishing, company B, process 2.

4.64 Sensitivity of methods (EcoIndicator and Critical Volumina), shown with results from case study D.

[8]http://www.ecoinvent.ch/

[9]Personal communication at LCA seminar in Thailand.

[10]ISO 14000 gives the term 'significance' for impact assessment in general. Before harmonization there were differences by a factor of up to 3200.

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reduction of only about 1%, while the same change with EcoIndicator 95 produced a reduction of 9% (Table 4.16).

Case study A, carried out in 2000, was confronted with two problems. First, as the earlier LCA methods did not rate water consumption, it was difficult to elaborate appropriate LCA results for cotton growing (Schaerer 2001). For the same reason BOURA (2001b) restricted the results of her cotton study to a simple process tree for assessment, instead of the existing LCA methods. Second, only a few pesticides were listed in the early SimaPro database. The method of Margni *et al*. (2001) was applied for part of the study, because they provided such data on pesticides, which disabled comparison with earlier studies. In between, additional methods such as CML 2000 basic (Margni *et al*. 2001) were developed, where newer pesticides were assessed (Humbert 2003, Charles and Jolliet 2003). Future LCA in agriculture should be calculated on this basis, maybe by means of specific software (see also page 284).

In the database of the software a particular electrical energy production has to be selected. Generally there are national mixes for energy production available. In practice these mixes become irrelevant, because electricity is traded all over Europe. As a consequence either the European electricity mix or a national mix can be applied, resulting in different values, because some nations have better environmental performance of their prime electricity source, and others have a worse performance than the average European prime source. Some mills even have their own electricity supply from hydropower, coal, etc. The production of 1 kWh European mix is associated with 928 μP while the equivalent of hydropower is charged only with 9.35 μP, a difference by a factor of 100. The system modeling should also determine which prime source should be selected for calculation.

Another problem arises from the choice of software with a given database and a number of methods. Although the software OeBeB.Pro (case study

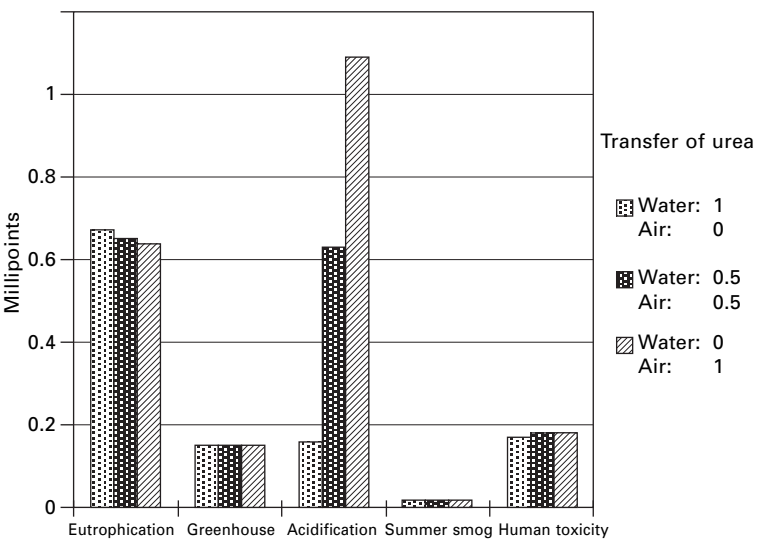
Table 4.16 The contribution of fossil energy based SO_2 emissions to impact categories depends on the method (calculation model)

Method	Contribution of SO_2 to impacts caused by prime source oil (% of total)	Contribution of SO_2 to impacts caused by 60% oil and 40% gas (% of total)	Contribution of SO_2 to impacts caused by prime source gas (% of total)
CML nutrification	85	80	1.1
CML human toxicity	86	83	1.1
EcoIndicator 95	76	68	0.5
Critical Volumina normalization (CH)	90	89	3

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B) applied by Stokar (1996) was designed for textile processes, it could not be judged to be superior to the SimaPro software used in the second study (Zwicker 1997). While the textile-specific software probably facilitates the filling in of the inventory data, it provides fewer methods to use. SimaPro, on the other hand, requires a certain skill to build up the inventory, but due to its general system it is compatible with any system (not only textile), allowing LCA from cradle to grave. Also it is essential that software has an excellent database, which is set up periodically. In our study we had to harmonize the data set on energy to achieve coincidence.[11] Our inventories in the two computer tools showed differences for the two substances (only in OeBeB.Pro) and two others (only in SimaPro). Differences slightly greater than 1.5× were found for N_{tot}, COD, BOD and DOC. A similar result might be expected in comparing general LCA software and the agriculture-specific SALCA database (Gaillard *et al*. 2006). With EcoIndicator 99 the user is given several perspectives that outline ethical questions (Leist 2004), representing merely academic values.

The choice of the method is also essential for the estimation of transfer coefficients because some methods rate emission to water higher than to air and vice versa (see Fig. 4.65). This is particularly the case in finishing, where measurements are missing or impossible because of mixed process



4.65 For wet processes transfer coefficients to water and air have to be determined. Based on the calculation models, the environmental impacts become different when transfer coefficients to water and air are changed from 1:0 to 0.5:0.5 and 0:1.

[11]Before harmonization there were differences by a factor of up to 3200.

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emissions. Also shown in Fig. 4.65 are the different consequences for the impact categories which lead to different rating of the results. One must, however, keep in mind that a particular formula is chosen for a desired effect on the fabric, a property that is tested according to quality requirements. Consequently the function is set by the quality requirements. The failure of an appropriate transfer coefficient is minor compared with what can appear through inappropriate measurement, as Wiederkehr (2004) showed. For a calculated emission model and later tested prototype of a diesel catalyst he found large differences in the LCA results.

As methodology is steadily developing, permanent discussion between theory and practice is essential. The Swiss LCA forum is one of the best-known platforms for such exchanges.[12]

While taking into account uncertainties even in well-known systems with a detailed database, the application of simplified LCA, as shown by Walenius-Henriksson (2004a), may lead to only slightly less accurate results. For the evaluation of products with short lifetime and also for eco-labeling purposes they seem to be sufficient. In the future the application of a planning tool, including data from simplified LCA, as developed in Section 4.8, might be economically and ecologically preferable to the detailed LCA studies.

4.7 Costs

4.7.1 Costs and LCA in cotton growing

LCA results should be compared to costs. For case study A the cost analysis has been carried out on the level of the system model for LCA, meaning costs for personnel are not included. Because tillage and harvest of this case study in the USA are machinery[13] operations, this seems to be a passable way. In the organic scenario agrochemicals are replaced by mechanical operation with specially developed machinery. As shown in Fig. 4.66 costs are not correlated with LCA results but depend on the farmer's practices. Both results, LCA and costs, are calculated per kg cotton. In the scenarios WRR and WOrganic we find low environmental impacts and low costs. As the results of LCA and costs are calculated per kg cotton the effect becomes evident.

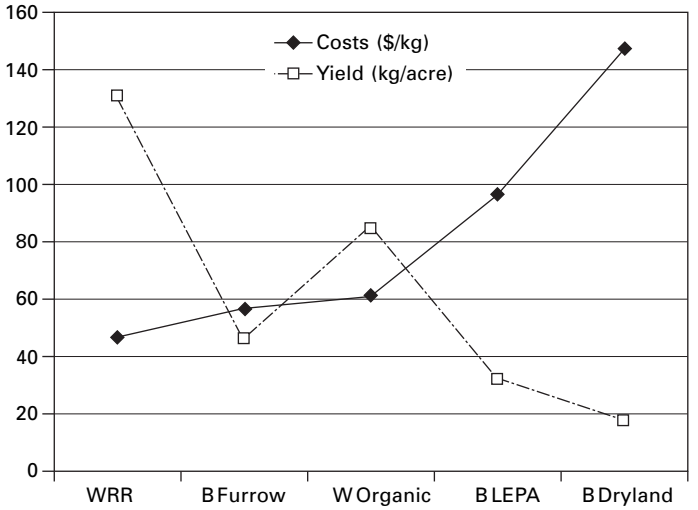
LCA results are negatively correlated with yield in such a way that low yields produce high environmental impacts (Fig. 4.67).

Farmer W produced high yields on both scenarios WRR (GMO) and WOrganic, and spends comparably less money on 1 kg cotton in both scenarios (Fig. 4.68), while farmer B spends more money per kg, which

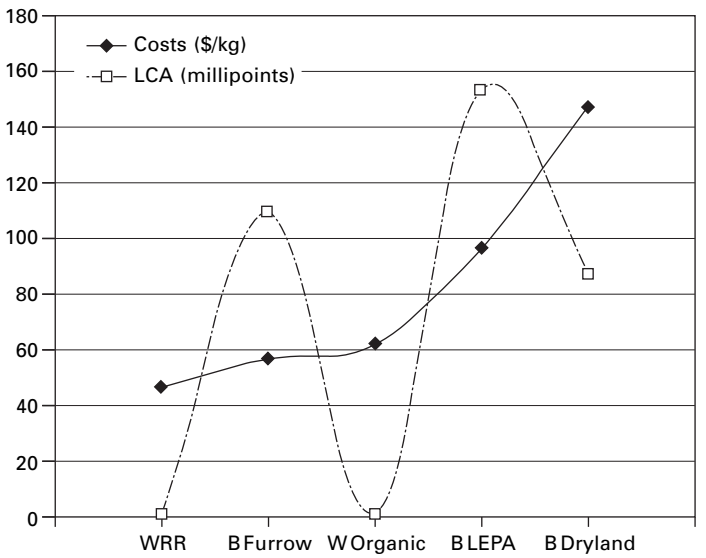
[12]www.lcainfo.ch

[13]Personal communication with organic farmers in Texas.

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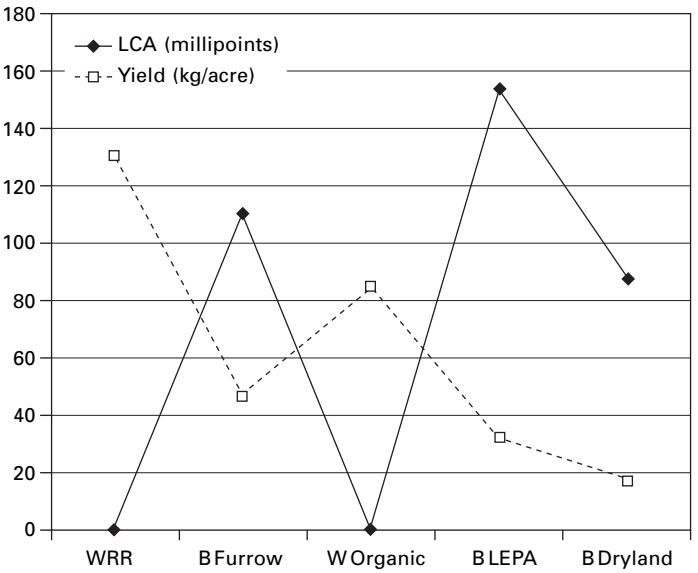
4.66 Comparison of costs ($ per kg) and yield (kg per acre) of the five scenarios of case study A.



4.67 Comparison of LCA results (millipoints) and cost ($ per kg) of case study A's five scenarios.

is especially visible in the WDryland cotton. In this scenario no irrigation was done, which consequently saved costs for these operations. But due to the very low yield, all the other inputs such as agrochemicals and tillage produced the highest costs of all scenarios.

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4.68 Comparison of LCA results (millipoints) and yield (kg per acre) of case study A's five scenarios.

4.7.2 Costs of organic cotton versus conventional cotton products

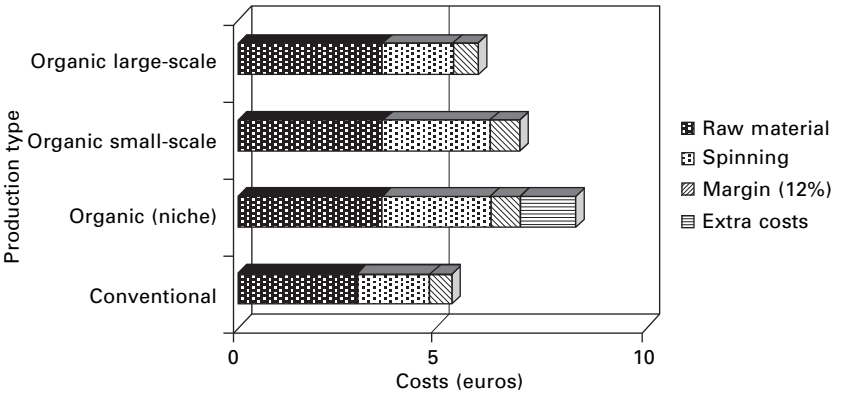
Certified organic cotton is considered to be costly compared to conventional cotton. Especially in areas where cotton is grown with manual work the effort for weeding is high, because no herbicides may be applied. But also the education of farmers and the certification processes are cost drivers. In case study A, BDryland cotton was the most expensive, mainly due to its low yield. However, costs did not exactly show the same ranking: WOrganic as the second best-yielding scenario entailed only slightly higher costs than BFurrow (the third best-yielding scenario). Considering yields and cost, one has to admit that 2001 was an extreme year regarding weather conditions.

The costs of organic certification become more prominent the smaller the number of cultivated acres, as Fig. 4.69 shows. Instruction and certification are the extra costs for a niche production. The comparison is made for yarn costs including spinning. In mills with mixed production the organic lines must be separated from conventional lines, in order to prevent flight of fibers that would contaminate organic cotton.

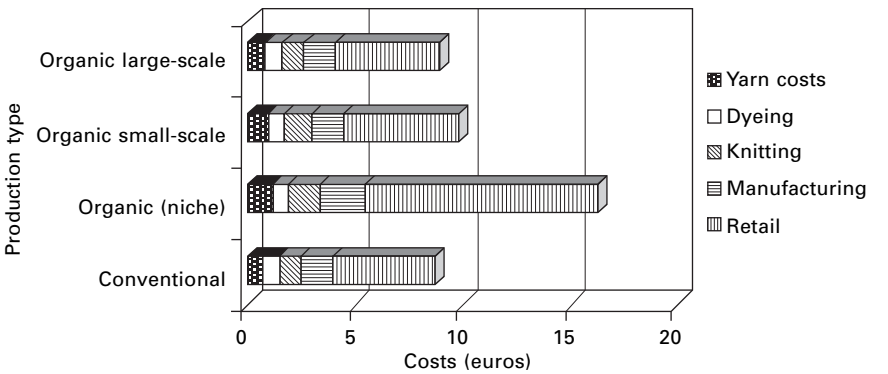
When analyzing a T-shirt we see that the fixed margin for niche production in retail increases the costs tremendously without additional effort (Fig. 4.70). The results are based on a study of the Maikaal[14] project in India.

[14]www.biore.ch

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4.69 Costs for certified organic cotton yarns based on different production scales compared to conventional cotton production.



4.70 Production costs for certified organic cotton T-shirts based on different production scales compared to conventional cotton production. Costs include all process adaptations along the value-added chain.

The empirical findings are in line with Hummel (1996), who showed that the fixed rate of net return in retail creates bad competition for organic cotton.

However, in India the economic situation for the farmers improved, because they saved money compared to the costs of expensive agrochemicals. Instead, they built up capacity to produce organic pesticides from the domestic Nim tree.[15] It is estimated that the organic farmer makes benefits of 25% compared to conventional cotton farmers. US organic cotton is faced with even greater problems, because market prices of the organic fibers are only twice the price of conventional cotton,[16] which does not cover their production costs. Besides

[15]P. Hohmann, REMEI, personal communication.
[16]LA REHEA PEPPER, personal communication.

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the differences between manually harvested and cultivated and machine tillage of organic cotton with reference to cost, the quality aspect for the market has to be investigated carefully. Organic SEKEM[17] cotton from Egypt is of extra long staple quality (ELS) and therefore has better market opportunities than Texas organic mid-staple cotton, of which only 80 to 85% is spinable. However, there may be alternative channels for organic cotton such as hygiene articles.[18] Mostly organic cotton projects are developing projects and require a high investment in social development, not only in education. The impact of such sustainable development is high in these developing countries. The SEKEM project in Egypt established a kindergarten for the women working on the field. It also launched a small domestic market with spinning and weaving. At the beginning of the project organic cotton was subsidized by the government, which increased the organically cultivated acreage. In Mali the cotton trading company Rheinhard invested not only in transportation infrastructure for cotton but also in healthcare systems for workers. Investments in sustainable cotton production always include investment in social and environmental systems.

As an option, Frisvold *et al*. (1999) analyzed the additional cost for genetically modified cotton but with higher yield.

4.7.3 Costs of textile technologies

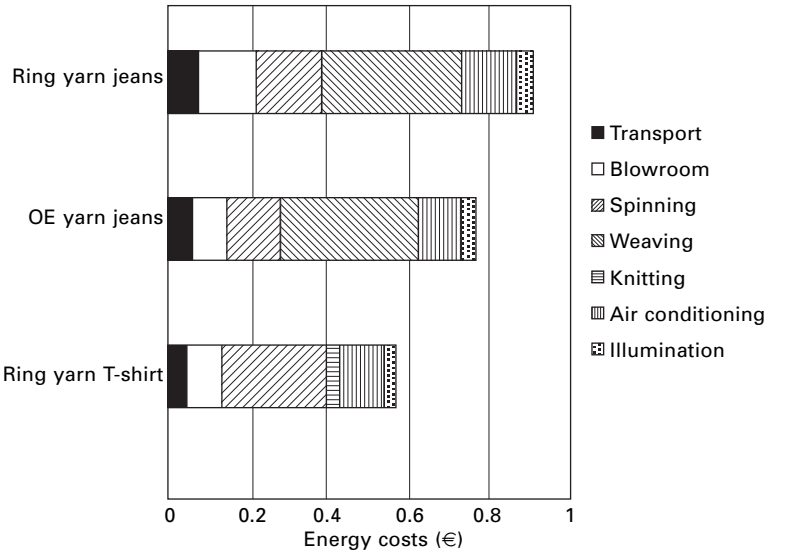
As for the production of fabrics different fibers and technologies can be applied, we must expect different costs per m^2 of fabric. Figure 4.71 gives the technology costs for the products of case study B. The comparison of the two staple spinning technologies with the same weight per m^2 indicates the lower costs of the OE spinning technology. The lower costs of the ring spun T-shirt with lower weight per m^2 are caused by the knitting technology compared to weaving technology.

In Fig. 4.72 the only filament product, a fashion PA 6.6 T-shirt, is compared to a conventional T-shirt of cotton staple fibers. The lower weight of the nylon fabric produces lower costs in filament spinning but equal costs in knitting for equal knitting loops. Finer loops of the nylon shirt would result in higher costs. The transportation of the raw material is also included in the system, whereby both distance and weight are higher for the cotton product.

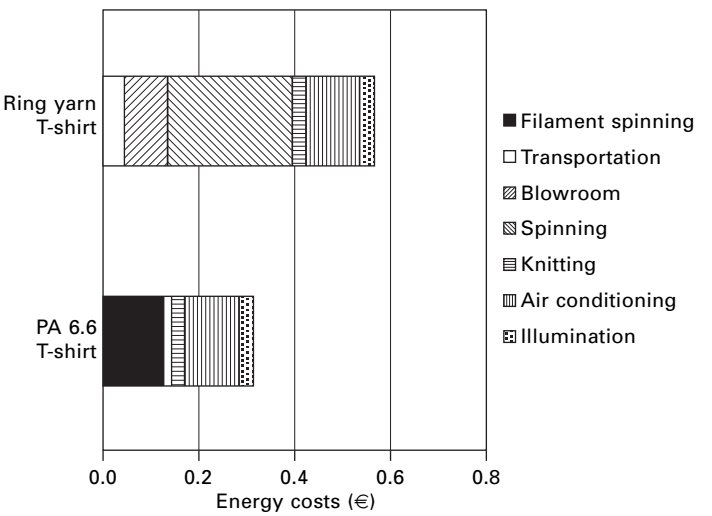
The comparison of knitting and weaving technology (Fig. 4.73) shows a clear cost advantage for knitting. But the difference becomes smaller or is even reversed if advanced weaving technology (multiphase weaving) with a high productivity is applied (see Chapter 3).

[17] www.sekem.com
[18] www.organicessentials.com

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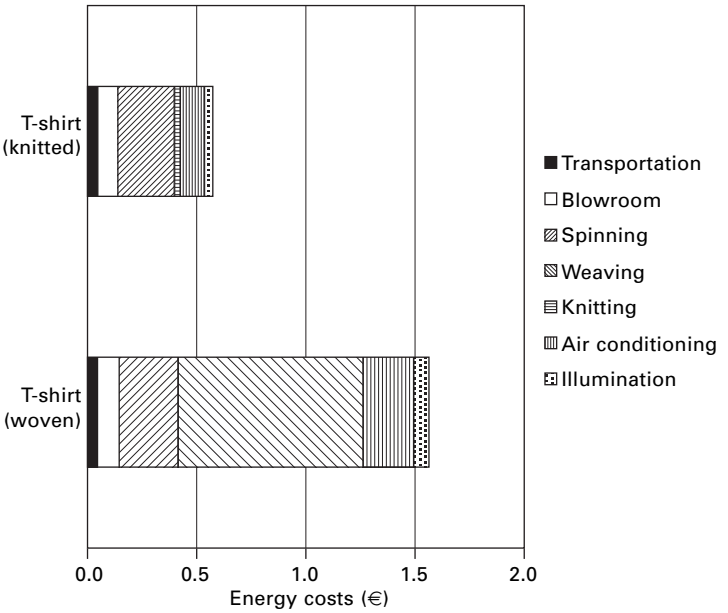


4.71 Energy costs (in €) vary considerably for different fabrics.



4.72 Which fibers are more attractive considering energy consumption? The processing of a T-shirt made of polyamide 6.6 is less energy consuming than for a comparable T-shirt made of cotton (fiber production excluded). These results do not include considerations of functionality of the two fiber types.

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4.73 Which processes should be favored? Knitted fabrics show better eco-performance based on lower energy consumption (kWh). Moreover, the productivity of the knitting technology is higher than that of the weaving technologies.

4.8 Introduction to ecological key figures (EKF)

4.8.1 The present situation in impact assessment

Considering the worldwide attempts to improve sustainable textile production in the industrialized and developing countries, measurements are requested to report and compare products and production. Numerous environmental labels and programs for textiles are on the market in order to attract the interest of consumers (see also Chapter 1). However, the scientific basis for these labels is unequal according to the ISO definition (ISO 14050). Only labels of type III with independent, third-party control of disclosed standards, based on a life cycle perspective, are scientifically accepted environmental labels (Caduff 2002). However, in the existing labels there is no orientation for consumers, and many of them lack a life cycle orientation (Tobler 1999a).

According to the ISO the focus can be on products and thereby on life cycle perspective (ISO 14040 ff) or on production represented by the eco-performance of individual companies (ISO 14030). The appropriate methodology to evaluate environmental impacts of products is life cycle assessment (LCA) (ISO 14001) with different methods in impact assessment.

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Methods for impact assessment in LCA (SETAC 1999) are still under development, as outlined earlier in Chapter 4.

However, in many companies data are not available on individual processes for selected products. Consequently allocation, either on a physical base or on economic values, becomes difficult (Nieminen 2002). Many data for specific textile production have to be collected and calculated into the functional unit(s) (Nieminen 1997, Dahllöff 2003a).

The data collection for life cycle inventories (LCI) of individual products is time consuming, as most often separate measurement programs for modeling and/or simulation (Creux and Weber 2002) have to be carried out. Life cycles of products generally span many companies, and confidentiality of data prevents access to inventory data.

Our previous work in process LCA (Stokar 1996, Zwicker 1997, Tobler 2000a, 2001c, 2002a, Luchsinger 2002) provided the significant indicators and the thereby affected impact categories. Textile specifications, on the other hand, combine desirable environmental aspects and quality data, available in the textile industry (Tobler *et al*. 2002, Ghituleasa 2002). Such specifications are not as detailed as LCA, but add the important quality aspect. The advantage of textile specifications lies in advanced business-to-business communication as well as business-to-customer communication. In its most extended version such specifications are applied for process control in industry.

Regarding the scope and functional unit, product development has to be studied. Textile products are extremely diversified under the global competition in product development, based on innovation and on specialization in textile technology and processing. Technology plays an important role in processing of different fibers, yarns and fabrics for desired properties. Most companies along the value-added chain diversify in many different products, according to the market demand. They change processes with high flexibility, whereby the batches may vary widely in quantity.

The implementation of best available techniques (BAT) (BREF 2003) as requested and elaborated under the European Union's Integrated Pollution Prevention and Control (IPPC) (Schönenberger 2002) provides a large, though not balanced analysis of environmental impacts of individual textile technologies. Yet BAT does not propose methods for comparable impact reduction, based on measurements and calculations (Tobler 2002b).

In this chapter a method called 'ecological key figures' (EKF) is proposed to fill the gap between the scientific requirements of a life cycle perspective and the availability of inventory data on the level of individual companies. The production of natural fibers is evaluated as growing regimes in agriculture that are equivalent to industrial processes for man-made fiber production (which is not modeled). Such life cycle oriented environmental performance

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is in accordance with ISO 14030 and can even be used for products. It can be applied in product development as well as for consumer information.

4.8.2 Theoretical scope of the ecological key figures

Each step in the value-added chain, from spinning to merchandising, is to be represented by means of an equation, whereby higher values stand for higher environmental impacts. The underlying mass and energy equations are based on characteristics of textile processing, including efficiency of resources. The scope also includes several requirements implied by a company's strategy in market orientation, technology portfolio and resource management. Environmental impacts are to be allegorized according to their global relevance and life cycle perspective. National factors such as legislation, policy and economy should not be represented in the EKF, though they highly influence the natural and human resource management. The scope of a theoretical model consequently is to be developed according to the following seven requirements:

1. Based on an individual company's production data
2. Reveals specific differences between different processes and technologies
3. Reveals differences in resource management
4. Includes all relevant global environmental impacts
5. Includes a life cycle perspective according to ISO 14040
6. Allows independence of national legislation
7. Allows independence of national costs (wages, energy, etc.).

The first three requirements implicate the company's business strategy. For benchmarking these parameters are the opportunities for changes in processes as well as resource management for optimization of the company's process management. These factors also represent a company's innovative potential and therefore combine economic and ecological strategies. This coincidence makes improvements feasible and likely. Points 3, 4 and 5 are based on the requirements by ISO 14040 ff. Their emphasis is put in the availability of data for an inventory, specifically of energy consumption and material flow indicators (input substances, mainly chemicals, and production outputs – emissions, effluents and solid waste). Points 6 and 7 allow the EFK to be applied globally. In a global market the independence of national factors is essential for competition. Nevertheless legislation and costs must also be considered, when areas for improvements are identified. Appropriate scale and scope should offer companies opportunities for optimization on the production site and give them evidence for improvements on national factors.

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4.8.3 Modeling and development of ecological key figures

The structure of the theoretical model has to include energy and mass relations from textile technology and processing as well as life cycle inventory and impact assessment. This is developed by mass equations, representing textile processing, and energy and substance equations, representing environmental inventories. For an impact assessment simplified weighting factors are introduced. Such modeling of the value-added chain takes the characteristics of specific products into account. The more accurately the model's factors are determined, the more precisely options for improvements can be identified.

Based on textile specifications of textile process technology (see Chapter 3) and the LCA results (Chapter 4), a system of mass, energy and substance equations have been developed. The value-added chain is represented as a series of individual production sites (farms and companies) consisting of fiber production, fiber preparation, yarn production, fabric production (weaving, knitting or non-woven), finishing, manufacturing and merchandising. In integrated companies (e.g. spinning and weaving) individual key figures are to identify for all sections. The functional unit, defined in LCA (ISO 14040), is set as the output of each production site in the value-added chain. Consequently inputs and outputs are defined between production sites. This procedure allows evaluating both an individual company and a product line in sourcing.

While mass, energy and chemical equations are defined by processes, simplified impact assessment models have to be evaluated. One model, adaptive for the entire system of EKFs, was found in the impact categories of the LCA method EcoIndicator 95 (see Table 4.17), because these categories show the best match with impacts affected by textile processing.

As the prime energy sources held an important position and their exergy and impacts differ, a weighting factor is applied according to Finnveden (1998) (see Table 4.18).

The coefficients represent the environmental impact by different prime sources. Optional models were developed and evaluated in practical applications (see Section 4.4). A very simple model can be found by identifying renewable and non-renewable energy (see Table 4.19).

A third model is based on CO_2 emissions caused by energy consumption (Table 4.20). The weighting factors are based on the so-called national energy mix, thus the percentage of the individual prime sources. It will be applied for comparison with Section 4.4 of this chapter.

Assuming that companies are specialized in a defined quality segment, individual formulas are based on annual production of average quality.

The presented EKF here focus on environment and ecology. They can be

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Table 4.17 Weighting factors according to EcoIndicator 95

Impact category	Impact reference	Weighting factor
Greenhouse effect	kg CO_2-equivalent	wGE = 2.5
Ozone depletion	kg R11-equivalent	wOD = 100
Acidification	kg SO_x-equivalent	wAC = 10
Eutrophication	kg PO_4-equivalent	wEU = 5
Heavy metals	kg Pb-equivalent	wHM = 5
Carcinogenic substances	kg PAH-equivalent	wCS = 10
Winter smog	kg SO_2-equivalent	wWS = 5
Summer smog	kg C_2H_4-equivalent	wSS = 2.5
Pesticides	kg CO_2-equivalent	wP = 25

Table 4.18 Coefficients for individual prime energy sources

Energy sources	E95 factor
Gas	200.00
Petroleum products	640.00
Water power	2.59
Coal	640.00
Nuclear power	20.9

Table 4.19 Energy weighting: renewable vs non-renewable

Renewable energy	Non-renewable energy
Water power	Petroleum
Solar energy	Gas
Wood	Nuclear power
Biomass	Coal
Wind	
Waste combustion	

Table 4.20 Coefficients for CO_2 based energy weighting

Country	CO_2 (t/kWh)	Weighting factor
Switzerland	0.000002	0.2
Germany	0.000498	49.8
Romania	0.001120	112
Lithuania	0.011594	1159.4
Austria	0.000157	15.7

complemented to a simplified index for sustainable development, if costs for material, energy and wages (economic indicators) as well as working hours (social indicators) are added. However, by adding economic and social values, such key figures for sustainability become nationally and company specific. The same model type should be applied for all EKFs.

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4.9 Theory for ecological key figures (EKF)

The models for ecological key figures are developed for all production sites in the value-added chain of (cotton) textiles. They have been evaluated in practical applications for spinning and weaving processes (see Section 4.4).

4.9.1 Cotton growing

The inputs in cotton growing are cotton seed (in kg), irrigation water (in m^3/ha), pesticides and agrochemicals (in kg/ha) as well as energy (in kWh). The input unit is seed input (kg/ha cotton field) and the output is measured as cotton bolls (kg cotton bolls). However, yield efficiency is the most important parameter, because all inputs are related in mass to the cultivated area:

SE = seed input (kg/ha cotton)

CB = yield output (kg cotton bolls/ha land)

Energy and water consumption represent important parameters, which are defined as the energy index (EI) and water efficiency (WE) in two equations.

Impact categories

For the calculation in EKF of growth the impact categories and weighting factors of EcoIndicator 95 (E95) are applied. The following indicators can be identified: Energy (E), Pesticides (P), heavy metals in agrochemicals (AC), eutrophication in artificial fertilizers (F) and organic matter (OM), as shown in Table 4.17. Agrochemicals like defoliants, harvest aids, maturing agents, etc., and pesticides are multiplied by the average toxicity class (numbered 1–5). The resulting formulas are listed in Table 4.21.

A considerable difference is pointed out by distinguishing between artificial fertilizer (Wf) and organic matter (OM), whereby the later is considered a natural source with a natural environmental impact. Any other auxiliary

Table 4.21 Parameters in cotton growing with corresponding impact categories E95 and units

	Impacting substance	Unit	Impact category	Value	Formula
P	Pesticides	kg/ha	P	25	25 * P * tc
AC	agrochemicals like defoliants, maturing agents, harvest aids, etc.	kg/ha	HM	5	5 * AC * tc
F	Artificial fertilizers	kg/ha	EU	5	5 * F * tc
OM	Organic matter	kg/ha	wEU	5	5 * OM

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made from surrounding natural sources, like organic pesticides, is treated the same as organic matter.

Water efficiency

Water can be applied in several forms of irrigation with surface water (ISW) or ground water (IGW) and as rainfall (R). Because the use of ground water is not sustainable in many areas this parameter is weighted with a factor of 2. Water efficiency (WE) is calculated as:

$$WE = ISW + 2IGW - R \tag{4.1}$$

where ISW = irrigation with surface water (m^3/ha cotton), IGW = irrigation with groundwater (m^3/ha cotton) and R = rainfall (m^3/ha cotton).

Energy index

Energy consumption (EC) is also defined in a separate equation and includes fossil energy (E_{foss}) for cultivation and irrigation equipment and water wells, if the latter is not operated by electrical energy (E_{el}). Additionally the specific energy coefficients can be applied, taken from Table 4.18.

$$EI = E_{foss} + E_{el} \tag{4.2}$$

where E_{el} = electrical energy (kWh/ha cotton) and E_{foss} = fossil energy (kWh/ha cotton).

Theoretical model for cotton growth

In the theoretical model the two equations are combined with the formulas of the impact categories. The factors a, b and c are introduced for mathematical handling of the factors and to make the EKF dimensionless.

$$EKF_{Grow} = \frac{(a*WE) + (2.5b*EI) + 25c(P*tc) + 5c(AC*tc) + 5c\,(F-OM)SE}{c * CB} \tag{4.3}$$

Without the factors a, b and c the common unit of equation (4.3) is:

$$\frac{m^3 * kWh * \frac{kg}{ha}}{\frac{kg}{ha}}$$

For a dimensionless value the factors are defined as

$$a = kWh * kg/ha$$

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$b = m^{3*}$ kg/ha

$c = m^3 * kWh$

4.9.2 Ginning

In the gin a mechanical separation of cotton seed and cotton lint (fibers) takes place. Input for the cotton ginning processes are cotton bolls (CB), packed in modules, if harvested by machinery, or delivered in baskets from manual harvest. The output of a gin is lint production (LP) and seed production (SP), generally calculated in kg yarn. This information sets the two functional units.

CB = input: cotton bolls (kg cotton bolls/ha)

LP = output: lint production (kg lint/kg cotton bolls)

SE = output: seed production (kg seed/kg cotton bolls)

The EKF for ginning is based on three parameters: energy, ginning technology and mass. These parameters are defined in three equations, as the energy index (EI), the ginning index (GI) and the lint efficiency (LE).

The main environmental impact is energy consumption applied as electrical energy (E_{el}) for the gin stand, the transportation by air, the lint cleaners, the bale production, etc. Fossil energy (E_{foss}) is used for heating in the dry towers. Sometimes alternative energy (E_{alt}) is applied from CO_2 neutral resources, which has to be considered in the energy index.

Energy index

$$EI = E_{el} + E_{foss} - E_{alt} \quad 4.4$$

where EI = energy index (kWh), E_{el} = electrical energy (kWh) and E_{foss} = fossil energy (kWh).

Ginning Index

$$GI = \frac{1}{NLC} \quad 4.5$$

where NLC = number of lint cleaners.

Besides the desired cotton lint (LP) a considerable amount of cotton seed (SP) and a smaller amount of 'waste' are generated. If this waste is contaminated with pesticides or other harmful agrochemicals, it has to be treated as trash (theoretically) and is incinerated for heat production or disposed of in landfills. Organic matter (OM) of cotton, left on the field,

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is considered as a co-production of the ginning and therefore beneficial. If genetically modified cotton is ginned, the seed may not be used for cotton production and has to be treated like organic matter.

There may be differences in the input to the gin if the farmer uses a 'field cleaner' for removal of organic matter attached to the harvested cotton balls. This organic matter is left on the field.

In the equation for lint efficiency (LE) the output of cotton lint (LP), cotton seed (SP), organic matter (OM) and contaminated trash (T) is weighted accordingly.

Lint efficiency

$$LE = \frac{SP + OM}{T} \tag{4.6}$$

where T = trash (kg waste for incineration), OM = organic matter (not contaminated) (kg OM) and SP = seed production (kg seed).

Theoretical model for ginning

In the theoretical model the weighting factor (w) for impact assessment has to be included. Energy consumption contributes to the greenhouse effect, whereby the w_{GE} is defined as 2.5 (see Table 4.19). The combination of equations (4.4), (4.5) and (4.6) gives:

$$EKF_{Gin} = \frac{w_{GE} * a * EI * GI}{LE} \tag{4.7}$$

$$EKF_{Gin} = \frac{w_{GE} * d * (E_{el} + E_{foss} - E_{alt}) * NLC * T}{SP + OM} \tag{4.8}$$

The dimension of equations (4.7) and (4.8) without factor d is kWh/kg, whereof the reciprocal value is determined:

d = kg/kWh

4.9.3 Spinning

The input for the cotton spinning process is lint production (LP), packed in bales of 220–240 kg. The output of a spinning mill is yarn production (YP), generally calculated in kg yarn. This information sets the two functional units:

LP = lint production (input) (kg lint/kg cotton bolls)

YP = yarn production (output) (kg yarn)

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The EKF for spinning is based on three parameters: energy, spinning technology and a fiber mass. These parameters are defined as the energy index (EI), the spinning index (SI) and the fiber efficiency (FE) in three equations.

The main and only impact in spinning processes is energy, whereby companies often have a potential for energy reduction in air conditioning and illumination. For 1 kg yarn the energy index (EI) is defined in equation (4.9).

Energy index

$$EI = EI_{proc} + EI_{AC} + EI_{il} \tag{4.9}$$

where EI = energy index (kWh), EI_{proc} = energy for processing (kWh), EI_{AC} = energy for air conditioning (kWh) and EI_{il} = energy for illumination (kWh).

The fineness, and to a smaller extent also the twist of a yarn, are strongly correlated with process energy: the factor in spinning energy is defined by the fineness in tex, whereby 1 tex = 1 g/km. Therefore a spinning index (SI) is defined in order to equalize the energy consumption.

Spinning index

$$SI = YP * F \tag{4.10}$$

where SI = spinning index, YP = yarn production (kg/a) and F = fineness (tex) = (g/km).

This simplified equation neglects the fact that energy in blowroom, carding and drawing are not correlated with the fineness of the yarn. Also different spinning technology is not included. Inherent differences between spinning technologies due to the specific processes shall be indicated by specifying the spinning type Y as ring spinning (RS), compact spinning (CS), rotor spinning (OE) or friction spinning (FS). The yarn output is further specified with X as carded (c), combed (cd) or twinned (tw) type in order to achieve comparability.

The fiber efficiency includes the different fiber fractions in processing: recycled fibers (RF), fiber waste (FW) and combers (C).

Fiber efficiency

$$FE = \frac{RF - C}{FW} \tag{4.11}$$

where FE = fiber efficiency (kg/kg), RF = recycled fibers (kg/a), FW = fiber waste (incineration) (kg/a) and C = combers (kg/a).

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Fiber efficiency Theoretical model for spinning

In the theoretical model the weighting factor (w) for impact assessment has to be included. Energy consumption contributes to the greenhouse effect, whereby the w_{GE} is defined as 2.5 (see Table 4.18). Factor e is introduced for a dimensionless result. The combination of equations (4.9), (4.10) and (4.11) gives:

$$EKF_{Spin} = w_{GE} * a * EI * SI * FE \quad 4.12$$

$$EKF_{Spin} = \frac{2.5 * e * (Eproc + Eac + Eil) * (YP * F) * (FW)}{(RF - C)} \quad 4.13$$

The dimension of equation (4.13) is:

$$\left[\frac{kWh * kg * kg * km}{1000}\right]$$

Factor e is defined by the dimension of the EKF as

$$\left[\frac{1000}{kWh * kg^2 * km}\right]$$

The EKF for spinning may only be used for comparison of yarns with similar specifications. Differences consequently are related to process technology and good management practice.

4.9.4 Weaving

The textile input for weaving is yarn production (YP) for warp (W) and the weft. The output is the woven fabric, indicated as the length of a batch with a defined weight per m^2.

YP = input (kg)

FP = output (g/m^2)

The EKF for spinning are based on four energy indices and a sizing index, whereby the mass equation is applied. The main environmental impact categories are greenhouse effect, due to energy consumption, and possibly eutrophication caused by the sizing agent, whereof the weighting factors are determined (see Table 4.19).

Mass equation

The relation between yarn input (kg) and fabric output (g/m^2) is calculated by multiplying warp and weft (filling) density (DW and DF) with the weight of the corresponding yarn.

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Theoretical model for spinning

DW = density warp (counts per cm)

DF = density filling (counts per cm)

The weight of 1 m length of yarn is calculated from the relation of the yarn fineness F:

F = tex = g/1000 m

FW = fineness warp yarn (tex)

FF = fineness filling (tex)

The mass equation for 1 m^2 is defined as:

$$1\,m^2 = \frac{D_W * F_W + D_F * F_F}{1000} \qquad 4.14$$

The production of a batch is given with 1* weight per m^2:

$$FP = 1 * (D_W * F_W) + (D_F * F_F) \qquad 4.15$$

Sometimes the batch is calculated as the product of fabric length and fabric width.

Energy indices

Energy requirement in production is correlated to the fabric quality, specifically to the warp and weft density per m^2. Accordingly the quality differences in weaving are caused by the fineness and density of the woven fabric. Therefore energy indicators (EI) for the different processes of weaving preparation (WP), sizing (S), infrastructure (IF) and weaving (W) are divided by the corresponding density of the warp or weft.

Energy index for weaving preparation (warping)

$$El_{WP} = \frac{E_{WP}}{FP * D_W} \qquad 4.16$$

where E_{WP} = energy for weaving preparation and D_W = warp density (number).

Energy index for sizing

$$El_S = \frac{E_S}{FP * D_W} \qquad 4.17$$

where E_S = energy for sizing and D_W = warp density (number).

If no sizing agent is applied this index becomes zero.

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Energy index for weaving

$$El_W = \frac{E_W}{FP * D_F} \quad 4.18$$

where E_W = energy for weaving and D_F = weft density (number).

Energy index for infrastructure

$$El_{IF} = \frac{E_{IF}}{FP} \quad 4.19$$

where E_{IF} = energy of infrastructure.

All energy indices are based on the assumption that the compartments for warping, sizing and weaving as well as for infrastructure can be measured individually.

Sizing index

Sizing is necessary for cotton warps and others (PET, PBT, microfibers, etc.). It is expressed by the energy index (4.17) and the chemical oxygen demands (CODs), originated by the sizing agent. For non-sized fabrics this part of the equation becomes zero.

$$IS = \frac{COD_S}{FP} \quad 4.20$$

where COD_S = sizing agent/a (kg).

Theoretical model for weaving

The EKFs for weaving are constructed by adding the energy indices for the weaving preparation, the weaving and the infrastructure as well as the product of the factors sizing index and energy index for sizing. The weighting factor for energy (greenhouse effect) and COD (eutrophication) are introduced from Table 4.19 as well as the factor d for a dimensionless equation.

$$EKF_{Weav} = 2.5d * (EI_{WP} + EI_W + EI_{IF}) + (2.5EI_S * 5IS) \quad 4.21$$

Factor d is the reciprocal value of the energy index dimension of equations (4.16) to (4.19), which is the same as in ginning (see Section 4.9.2), thus:

$$d = kg/kWh$$

Woven fabrics may be compared only if they are similarly specified. Differences are then related to the applied weaving technology and good plant management.

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4.9.5 Finishing

Finishing is by far the most diversified part in the value-added chain and it bears the greatest potential for environmental pollution. Good finishing practices mean management for optimization of different batches. Often not an individual product but the environmental improvements on a company level can be expressed in the ecological key figures.

Both input (FP from weaving) and output in finishing (finished fabric production) are fabrics, measured in weight per m^2. The properties and the weight of the output have been changed by processing. Therefore the shrinkage of the fabric due to processing has been calculated for the output. Consequently all values are related to the dimension of the finished fabric quality (FFP).

FP = input g/m^2

FFP = output g/m^2

The high energy demand for the heating of the bath and the steam production contribute to the greenhouse effect. The water consumption is a main characteristic for wet processing. Heat recovery as well as water reuse are often carried out for economic reasons and contribute to energy efficiency (EE) and water efficiency (WE), respectively. The high number of chemicals applied affects several impact categories.

The EKF for finishing are based on equations for energy and water efficiency combined with the impact indicators consisting of specific emissions to air and water.

Indices for output indicators

The inventory of chemical input substances is complex due to the lack of proper information on chemical content. Mostly it changes from season to season, following fashion trends. Consequently the output indicators are measured as listed in Table 4.22. They are defined in three mass equations according to their contribution to the effluent load (EL), to airborne emissions (AE) and to the neutralizing activity (NA). The number of individual formulas for processing of different fiber types and fabrics does not allow defining a product-related contamination of water and air quality. Instead the annual water and air quality is applied. In contaminated air and effluents many impact categories are affected besides GWP (for energy) and water consumption.

Among airborne emissions volatile organic compounds (VOC) and halogenated organic carbon (AOX) contribute to summer smog (SS) and the ozone depletion potential (ODP), respectively.

As the effluent parameters COD + Ptot + TKN + HM contribute to

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Table 4.22 Chemicals in finishing with contribution to impact categories and emission types air (A) or effluents (E)

Parameter		Impact category	Emission type	Unit
VOC	Volatile organic compounds	Summer smog (SS)/GWP	A	g/m^3
AOX_A	Halogenated organic C	Ozone depletion potential (ODP)	A	g/m^3
AOX	Halogenated organic C	Ozone depletion potential (ODP)	E	g/m^3
HM	Heavy metals	Heavy metals (HM)	E	g/m^3
COD	Chemical oxygen demand	Acidification/eutrophication/HM	E	g/m^3
TKN	Total K	Acidification/eutrophication/HM	E	g/m^3
P_{tot}	Total P	Acidification/eutrophication	E	g/m^3
NA	Neutralization agent	Acidification/eutrophication	E	g/m^3

acidification, eutrophication and HM, a common factor of 5 as an approximation is introduced. AOX is rated according to E95 weighting for ODP.

Dyestuffs contribute to COD, HM, TKN and Ptot, while auxiliaries show impacts on COD, HM, TKN, AOX, Ptot and VOC. The impacts by chemicals are weighted according to E95 (see Table 4.19) and are defined in the indices for the effluent load (EL), the contaminated air (AC) and as neutralizing index (NI) as shown in equations (4.22)–(4.24).

Chemical efficiencies

$$EL = 5 * (COD + Ptot + TKN + HM) + 100 * AOX \quad 4.22$$

$$AC = 2.5 * VOC + 100 * AOX_A \quad 4.23$$

$$NA = 10 * (7 - pH) \quad 4.24$$

The tendency for ever smaller batches is one of the dominant factors in finishing. This is represented in the equation by means of a specific batch coefficient (BC), defined as:

$$BC = \frac{B_L}{B_A} \quad 4.25$$

where B_L = batch length (m) and B_A = batch average (m).

The batch coefficient provides a benefit for those companies who have to work with small batches.

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Energy efficiency

$$EE = \frac{(E_{el} + E_{foss})}{(E_R)} \quad 4.26$$

where E_{el} = energy for processing (kWh/g * m^2), E_{foss} = Steam production from fossil fuel[31](kWh/g * m^2), E_R = Recovered energy (kWh/g * m^2).

Energy can be saved by heat exchange between fresh water and effluents and hot air, depending on processes applied.

$$WE = \frac{W_P}{W_R - W_E} \quad 4.27$$

where W_P = process water (m^3). W_R = reused water (m^3) and W_E = ejected water = (PW – RW) (m^3).

Water can be saved by reusing batches for rinsing processes in a counter-current system.

Theoretical model for finishing

The EKF in finishing includes the energy efficiency (EE) from (4.25) and the water efficiency (WE) from (4.26) as well as the output indices (4.21), (4.22) and (4.23), whereby EE is combined with the output indices for effluents. The batch coefficient (BC) from (4.24) equalizes different production lengths.

$$EKF_{Fin} = BC\ (2.5 * EE + WE\ (f * EL + g * NI) + f * AC) \quad 4.28$$

The factors f and g are introduced to make the EKF dimensionless. They are developed as reciprocal values from (4.22) and (4.23), from the smallest common denominator from (4.23) and (4.24) respectively, and are defined as follows. Again, as an EKF without dimension is aimed at, the following coefficients have to be applied:

$f = m^3/g$

$g = 1/m^3$

However, the output fabric FFP should be defined in more detail (see Chapter 3) in order to give proof for e.g. additional water consumption required by advanced quality. Also information on fiber type, fastness and surface functionality should be added to define the fabric more precisely and to allow comparison within similar properties or functions.

4.9.6 Manufacturing

Manufacturing takes a strong position in the value-added chain, insofar as the apparel type is determined as the functional unit for the EKF, e.g. ladies'

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upper wear, children's nightwear, underwear, etc., and thereby defines the manufactured apparel (MA).

FFP = input: finished fabric (g * m^2)

MA = output: weight of required mass or style (kg)

The required area for cut is determined in manufacturing. Consequently the output in kg per unit has to be multiplied by this area.

Manufacturing requires a certain amount of energy for sewing, depending on the style, the quality requirements and the apparel type, as well as energy for infrastructure. An indicator for waste efficiency is defined.

Energy index (EI)

The energy index includes process energy as well as energy for infrastructure, for which heating energy is divided by the heating degree days (to exclude local weather influences).

$$EI = E_{proc} + E_{il} + \frac{E_{heat}}{HDD} \qquad 4.29$$

where E_{proc} = energy for processing (kWh), E_{heat} = energy for heating (kWh), E_{il} = energy for illumination (kWh) and HDD = heating degree days [–].

Textile waste efficiency

$$TWE = \frac{(W_{Inc})}{W_R} \qquad 4.30$$

where W_{inc} = textile waste for incineration (kg) and W_R = textile by-products (kg).

Mass per apparel (MA)

The mass of the apparel (MA) is defined by the required mass multiplied by the weight per m^2 of the input (FFP). The unit is kg. This has to be measured because the merchandising calculation is based on numbers (or dozens).

Theoretical model for manufacturing

The theoretical model includes energy index (EI) and textile waste index (TWI) as well as the apparel mass:

$$EKF_M = MA * 2.5 * d\left(E_{proc} + E_{il} + \frac{E_{heat}}{HDD}\right) + TWE \qquad 4.31$$

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Factor d is the reciprocal value of the energy index dimension, which is the same as in ginning (see Section 4.9.2), thus:

d = kg/kwh

4.9.7 Merchandising

Merchandising takes a special position in the value-added chain as the added value is not from a production process but from the marketing process. This is a pure business process with decisions on where to buy or produce the merchandise. Input and output have the same units. But the order quantity (OQ) represents a key value for the business:

MA = input: weight of required area for cut (kg)

OQ = order quantity (–)

The main environmental impacts are the transports of goods (TG) and personal traveling (TP), besides energy for infrastructure. They all account for the greenhouse effect.

Transport index

The transport of the merchant includes all distances along the value-added chain from the growing area to the spinning mill (T_{fiber}), from there to the weaving mill (T_{yarn}), the round trip to the finishing company (finsihing as outward processing) (T_{fabric}), to the manufacturing plant (T_{man}) and finally to the market (T_{merch}).

$$T_G = \sum_{grow}^{merch} T * MA \qquad 4.32$$

where TG = transport distance of goods (km).

Depending on the transportation system, personal traveling in globally operating companies causes a considerable impact. As shown in Table 4.23 it is associated with different environmental impacts.

Table 4.23 Transportation system, rating (ecopoints) and weighting factors

Transportation system	Ecopoints	Weighting factor
Car	328	8
Train	42	1
Airplane continental	252	6
Airplane intercontinental	145	3.5

Source: UBP Umweltbelastungspunkte developed by Federal Office for Environment (BAFU) Switzerland.

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A simplified weighting factor (wf), representing the ratio of the different transportation types, is applied for personal traveling.

$$T_P = \sum_{car}^{airplane} T * wf \tag{4.33}$$

where T_P = personal traveling, T = travel distance per system and wf = weighting factor

$$TI = T_G + T_P \tag{4.34}$$

Energy index

$$EI = E_{el} + \frac{E_{heat}}{HDD} \tag{4.35}$$

where E_{el} = energy consumption in offices (kWh/g $*$ m^2), E_{heat} = energy for heating (kWh/g $*$ m^2) and HDD = heating degree days (–).

The energy index includes all energy for infrastructure: electrical energy as well as energy for heating with reference to the climate (heating degree days).

Theoretical model

The EKF in merchandising consists of the energy index EI (4.35) and the transport index (4.34), whereby the weighting factor for the greenhouse effect is introduced in the former. The output quantity represents the efficiency of the system:

$$EKF_{Merch} = \frac{(2.5 * h * EI) + (i * TI)}{OQ} \tag{4.36}$$

Factors h and i are introduced to make the EKF dimensionless. They are developed as reciprocal values from (4.34) and (4.35) respectively (h = 1/km: i = 1/kWh).

4.10 Applied ecological key figures (EKF) in spinning and weaving

The practicability of the theoretical models depends strongly on the availability of the required data. In our small experimental part we were given data with a great variation in accuracy. For this application we had to fit all data into one model and conclude whether the calculated EKF shows appropriate values for differentiation. The results will be presented in this section, whereas conclusions will be drawn in Section 4.11.

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4.10.1 Practically approved spinning model

Available data sources for EKF in spinning were provided by two companies, B (Luchsinger 2002) and D, from a survey. The data collected in the survey are given in Table 4.24 (Tobler and Scheidegger 2005). These data were equalized in data format for an annual production, because data on individual batches were not available in both cases. Ecological key figures were calculated based on equations for energy index (4.8) and yarn efficiency (4.10) according to the following equation (4.37):

$$EKF_{Spin} = \frac{2.5 * a\,(\Sigma\ EI) * YE}{YQ} * 10^5 \qquad 4.37$$

where: EI = energy index (kWh*tex/kg), YE = yarn efficiency (kg/kg), YQ = output (kg/tex) and a = factor (kWh/m^2).

The equation for yarn efficiency (YE) includes all types of waste and recycled fibers that are fed into the process, as well as combers. The higher the amount of waste for incineration, the greater becomes the dimensionless value for yarn efficiency.

Energy coefficients from Table 4.18 have to be introduced. In order to make the EKF_{spin} dimensionless a factor a is introduced. The factor a is defined as:

$$a = kWh/m^2$$

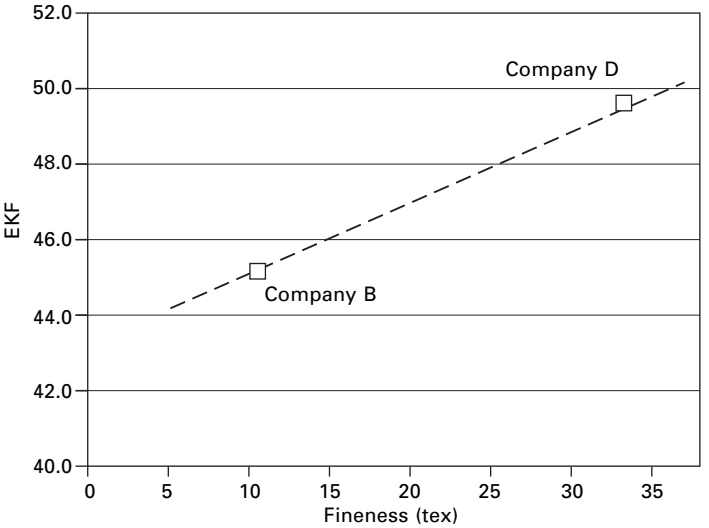
The spinning index was not applied as such, but was replaced by the quotient of the annual production (kg) and the yarn quality (tex). For a better visual representation a factor of 10^5 was applied.

Figure 4.74 shows the EKF of the two companies in relation to the average yarn fineness. Even if the data are based on annual production, it becomes

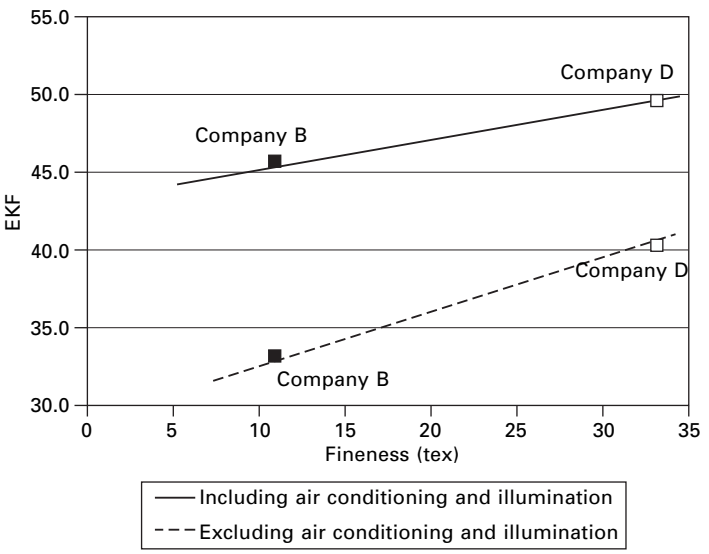
Table 4.24 Structure of the data collection for spinning

Data for spinning	Unit
Cotton (input)	(kg/a)
Yarn production	(kg/a)
Coarsest yarn	(tex)
Finest yarn	(tex)
Average fineness	(tex)
Waste (recycling)	(kg/a)
Waste (incineration)	(kg/a)
Short fibers	(kg/a)
Combers	(kg/a)
Waste (yarn)	(kg/a)
Total energy consumption	(kWh/a)
Energy for spinning	(kWh/a)
Energy for illumination	(kWh/a)
Energy for air conditioning	(kWh/a)

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4.74 EKF for the spinning processes of two companies, operating in different finenesses.



4.75 EKFs calculated with and without air conditioning and illumination.

evident that company B has the better environmental performance, because finer yarn generally requires higher energy consumption. The presented data do not allow conclusions on where company D has opportunities for improvements.

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Figure 4.75 shows the comparison of EKFs including and excluding air conditioning and illumination. It proves that company B applies less process energy (with a reduction of 12 units) but relatively more energy for illumination and air conditioning than company D (with a reduction of 7 units). Consequently illumination and air conditioning of company B show a small potential for reduction, whereas process energy should be reduced in company D. Only few companies are likely to provide such detailed data. This would favor the application of a simplified formula, based on total energy consumption.

4.10.2 Practically approved model in weaving

For EKF_{weav} two companies A and C (with three different products) provided data, besides company B (an integrated company with spinning and weaving). The data collection was based on the structure of Table 4.25. However, data were barely available in the desired detailed format. For company D data had to be extrapolated to annual production. Thus the energy indices from the theoretical model (4.16) to (4.19) were simplified to one index.

$$EI = \frac{EC}{P} * \frac{1}{DF * 1.2} \text{ (kWh/m}^{2*}\text{Nr/cm)} \qquad 4.38$$

Table 4.25 Specifications of the data collection

Data for weaving	Unit
Total warp yarn	(kg/a)
Coarse yarn	(tex)
Fine yarn	(tex)
Average fineness	(tex)
Total weft	(kg/a)
Coarse yarn	(tex)
Fine yarn	(tex)
Average fineness	(tex)
Sizing agent	(kg/a)
Annual production	(m^2/a)
Production	(m)
Lowest weight	(g/m^2)
Highest weight	(g/m^2)
Average weight	(g/m^2)
Total energy	(kWh/a)
Weaving preparation	(kWh/a)
Energy for sizing	(kWh/a)
Weaving energy	(kWh/a)
Illumination	(kWh/a)
Air conditioning	(kWh/a)

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where EC = energy consumption (kWh/a), P = annual production (m^2/a), DW = density of warp (nr/cm) and DF = density of filling (weft) (nr/cm).

Since the same warp and weft densities are not associated with equal energy consumption, an experimental factor of 1.2 is introduced (Kaspar and Kaspar 2000) for the weft yarn. The sizing index (4.20) is applied. The EKF_{weav} were calculated by introducing a factor of 10^4 to allow comparison with the same scale as in spinning ($EKF_{spin).}$

EI = Energy index (kWh/(Nr/cm))

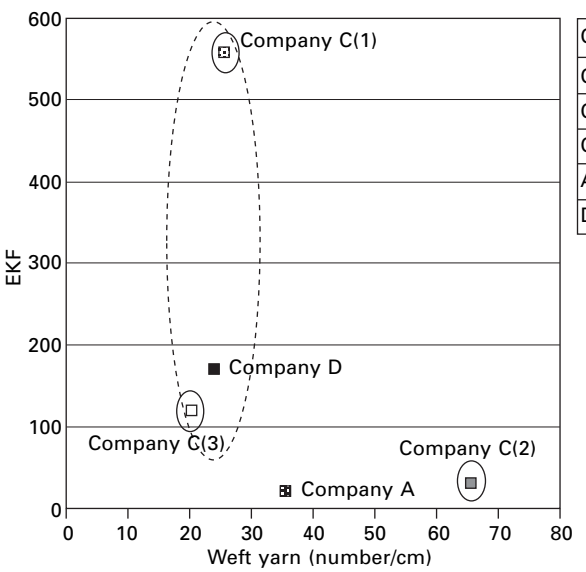
COD = Sizing index (kg/a)

a = Factor (m^2/kWh)

b = Factor (g∗m^2/kWh)

Results

The calculated results, based on production data, are presented in Figs 4.76 to 4.79. Figure 4.76 gives the EKF_{weav} in relation to the weft density. The calculated EKF are shown in the right part. The lowest value was found with company A, operating with a weft density of 36/cm. Interesting findings are the values for the different weft densities of company C, originating from



Company	EKF
C(1)	558
C(2)	31
C(3)	121
A	21
D	169

4.76 EKF of the weaving processes of different companies A, C and D, of which company C provided data on different products.

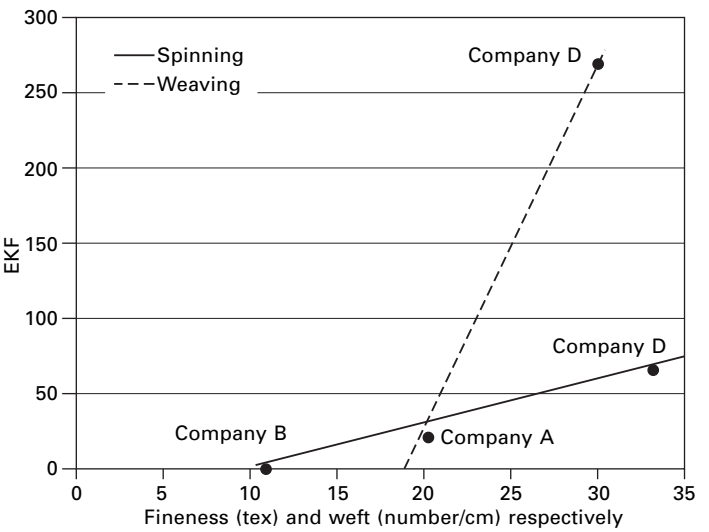
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three different product types: flat, pole and carpets with large differences in their weight per m^2 and produced with different weaving technology. Even though company D does not produce its own warp and therefore includes no warping and sizing processes, the values lay in a comparable area to those for company C (3). Company A, operating with median weft density, shows the lowest and best EKF value.

The values achieved in spinning and weaving can be presented in one graph as Fig. 4.77 shows. This was mainly achieved by means of the magnitude factor 10^5 for spinning and 10^4 for weaving. The comparison is based on the weighting factors from EcoIndicator 95 as shown in Table 4.19. For simplification one could also differentiate between renewable energy and non-renewable energy, applied in the specific case (see Table 4.19). The results for EKF_{spin} in Fig. 4.78 indicate that this simplification model reveals the efficiency of the individual company towards replacement of non-renewable energy. Company B shows not only better environmental performance but also better energy replacement strategies. Company B shows this better performance even with the production of finer yarns than company D.

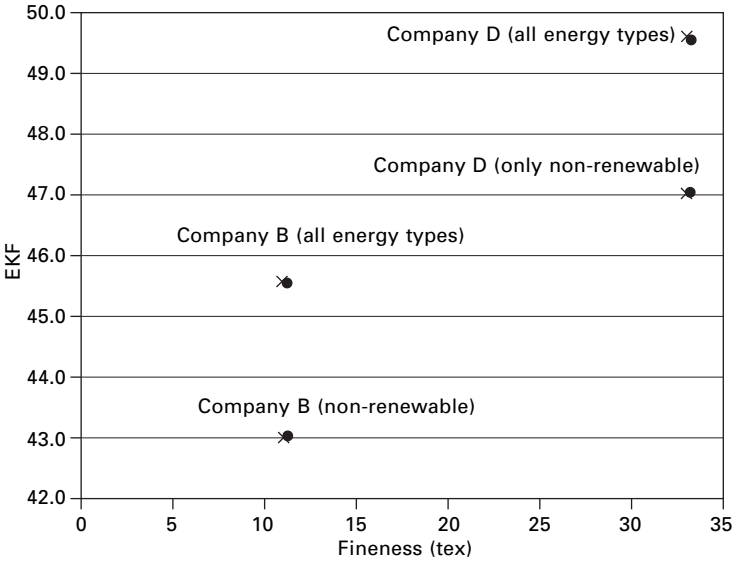
The simplification model cannot be applied for EKF_{weav} and other EKF with additional impacts to the energy consumption.

Another simplification model was tested with the CO_2 factor (see Table 4.20), a very common measure. Figure 4.79 gives the values for EKF_{weav} and EKF_{spin} which are comparable to the results gained with the EcoIndicator, except for the magnitude. Like the renewable/non-renewable model this simplification is valuable for simply energy-based processes.

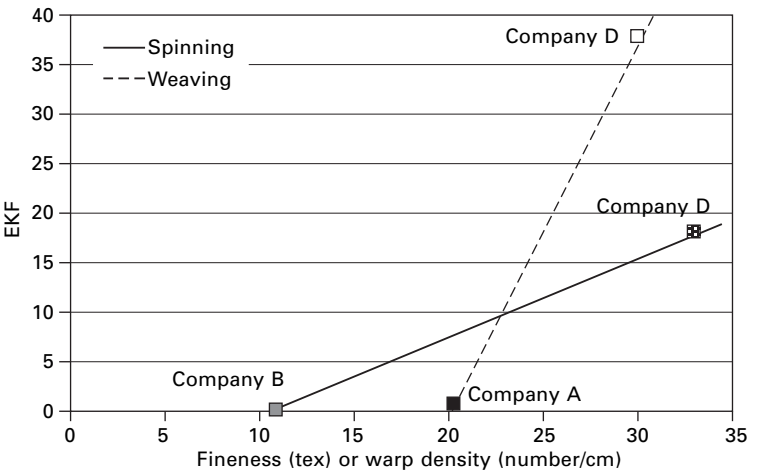


4.77 EKF of the spinning and weaving processes. The weighting factors for the individual energy sources were taken according to E95.

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4.78 EKF of the spinning processes: calculation based on non-renewable energy.



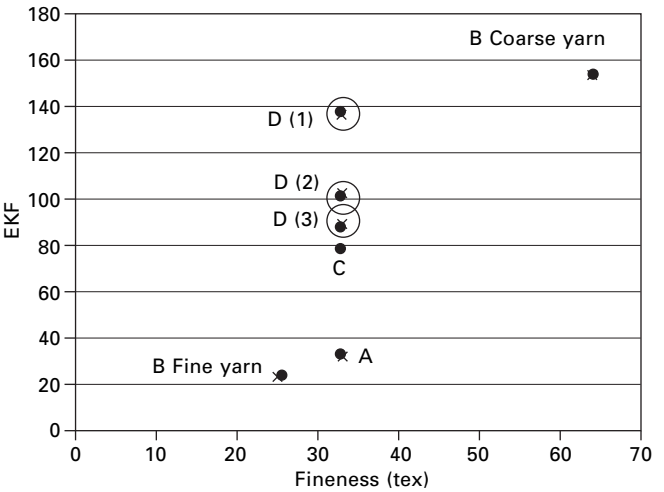
4.79 EKF of the spinning and weaving processes: calculation based on CO_2 emissions.

4.11 Discussion on ecological key figures (EKF) of textile products

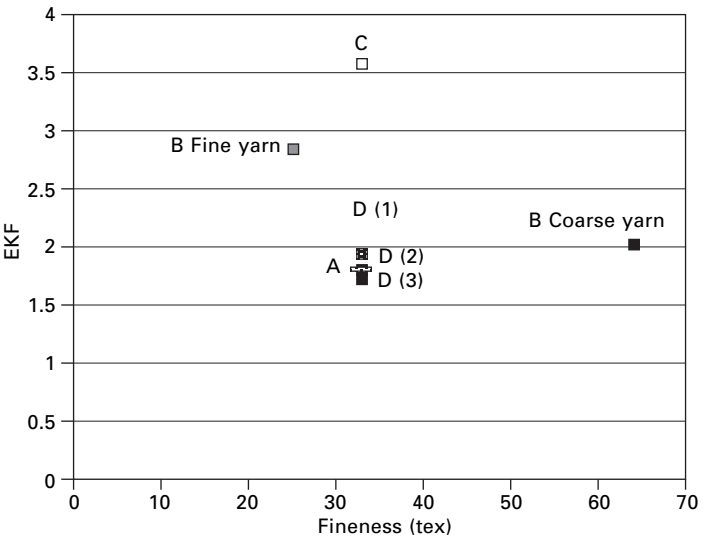
While the EKFs for spinning and weaving in the previous sections are calculated on company-based data, EKF for some specific products were

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calculated, based on the theoretical model (Fig. 4.80). As in previous examples on company data the simplification with CO_2 was calculated as well (Fig. 4.81). Different yarns are presented in Fig. 4.80 with EcoIndicator weighting and in Fig. 4.81 with CO_2 weighting. While the products of company D and the coarse yarn product of company B show a similar relation with



4.80 EKF for spinning for individual products from companies A, B and D (three different products).



4.81 EKF for spinning for products from companies A, B and D: calculation based on CO_2 emissions.

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both models, the CO_2 model calculates lower performance for the product of company A and the fine yarn product of company B. The differences are based on the individual CO_2 emissions of non-renewable energy resources like oil and gas.

4.11.1 Are the requirements for the model fulfilled?

The EKF by definition is based on an individual company's production data (requirement 1). It can reveal specific differences between individual processing (2) and if the data are available also according to the structure of the support processes on the production site. For the finishing processes this goal is clearly not achieved. But for the evaluation of all steps in a product's life cycle the EKF clearly reveals differences. This is also the case for the differences in resource management (3), where the merchandising company is given the decision and main responsibility. As the environmental impacts are derived from detailed LCA, all relevant global environmental impacts are included (4). By applying a step-by-step calculation along the value-added chain the EKF includes the required life cycle perspective according to ISO (5). Even if the EKF as an aggregated number may not be accepted as LCA by ISO, the individual parameters of the EKF can be used for documentation with an environmental product declaration (EPD). Both requirements – for independence of national legislation (6) and for national costs (wages, energy, etc.) (7) – are fulfilled. Apart from the requirements it must be clearly stated that the factors applied for the prime source of energy are different for individual countries (see UNCTAD 2004).

4.11.2 Database for ecological key figures

The presented ecological key figures allow optimization on company level as well as along the value-added chain. Assuming that companies do not change their processes for individual products, the EKF includes the main parameters that can be altered by a company: technology, formulas and substances (in this sequence of magnitude). As the EKF is focused on products, the general administration processes of a company are not included in any step. Consequently, electrical energy for business administration and heating energy are not taken into account, except in manufacturing, assuming a company would maximize it for economic reasons. However, if energy prices are low, this regulation may not take place. Companies in warmer climates may benefit from the warm temperature in the cold season. Illumination in production, however, is included in spinning, weaving and manufacturing, where it represents a considerable production factor.

The individual traveling costs of employees is only calculated in merchandising, because there its magnitude represents a significant impact.

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The decision to attribute all transports along the value-added chain to the merchandising company seems to be a hard one, but merchandising represents a key position for measures to take in sourcing. If B2B is increasingly used, some of the personal traveling will be reduced in the future.

When collecting energy data for LCA we found that most companies cannot identify the energy consumption on the individual machines. Most companies have data on the annual consumption per energy source and only a few know energy costs only. Often different departments like weaving preparation, weaving and control have individual electricity meters, whereas steam production is known only as a total consumption per week, month or year. The EKF sets on a structure with figures at least from individual departments. This can also be expected from integrated mills, including spinning, weaving and possibly finishing departments. The division in departments could be perpetuated in more detail within the finishing company, as presented in the proposed formula, but for simplicity reasons has been skipped.

More information is needed from finishing companies in the area of waste water and emission parameters. A matrix has been developed and modeled by Nieminen (2006) based on data of Finnish and Swedish companies. This matrix is currently adapted by COST Action 628 towards a European standard (Nieminen *et al*. 2007). Here traditionally surveyed parameters are collected for water and air, whereby a European standard is aimed at (see Table 4.26). The prime energy source is represented in the energy coefficients, while

Table 4.26 Effluent parameters, measured in different European countries

Finland	Germany	Switzerland
pH	pH	pH
°C	°C	°C
COD	COD	COD
		BOD
		TOC
		DOC
Tot-P		Tot-P
TKN	TKN	TKN
Cl^-		Cl^-
AOX	AOX	AOX
Cr	Cr	Heavy metals
Cr (VI)		Heavy metals
Cu	Cu	Heavy metals
Zn	Zn	Heavy metals
	S^{2-}	
	SO_3	
	SO_4	
		Conductivity

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emissions to air are restricted to chemicals applied in finishing. Because the products vary extremely in finishing companies, depending on fibers and the ever-changing required fiber properties, the EKF can set only basic standards.

4.11.3 Sensitivity aspects

Energy is one of the most significant environmental impacts associated mainly with global warming potential (GWP). Depending on the prime energy, acidification, heavy metals (HM) and possibly carcinogenicity may also be affected. For simplicity reasons these effects are replaced by the energy coefficients in Table 4.18.

Cotton growing and ginning is often located in developing countries, where different energy coefficients should be applied than are indicated for Europe in Table 4.18. The same counts for manufacturing, being very labor intensive and therefore often outsourced to countries with lower wages. The sensitivity of different energy coefficients could be reduced by applying the energy coefficients, based on the national data given in UNCTAD (2004).

Water consumption is one of the dominant impacts in cotton growing. As climate conditions vary over the globe, the presented EKF cannot give an adequate measure for a specific region. However, the water efficiency can be calculated. The question where to grow cotton cannot be answered by means of the EKF. In spinning, weaving and mostly in finishing a precise definition of the quality is required. Strictly, comparison may be made only between comparable qualities or functions in order to favor specific processing or technology.

The practical application

The sensitivity was also evaluated by means of the simplification models in application. The results showed that the overall energy consumption, as applied in the weaving application, did not allow differentiation between practices of companies. The very few data were certainly not enough to draw precise conclusions but to give evidence for better application. Two spinning companies provided detailed data for the energy index. We must expect, however, that other spinning companies could not provide such detailed data. Thus we cannot exclude possibility that the theoretical model is either too rough or too detailed.

The products calculated in weaving require more detailed data on energy (equations (4.16) to (4.20) of the theoretical model). As company A does not produce its own warp, the lower values compared to company C (3) with a comparable weft density could be explained by the lacking processes (warping and sizing), different product technology and/or different efficiency (see Fig. 4.76).

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The two simplification models, (a) renewable energy and non-renewable energy, and (b) CO_2 emission applied in practice, do not allow appropriate representation of environmental and technological influences. By applying the simplification models (a) or (b) we also get a conflict with requirement (7), the independence of national energy supply.

4.11.4 Comparison with LCA

A life cycle perspective is the major requirement for the EKF in agreement with the UNEP/SETAC life cycle initiative, clearly stating that a standardization of methods is not aimed at (De Haes 2003). The life cycle of textile products therefore can be modeled by means of ecological key figures. However, it would be unhelpful to start an absolutely new methodology. The EKF also follows strictly the indications of ISO 14042 considering life cycle impact assessment (LCIA).

Table 4.27 compares different LCA methods and UNCTAD criteria. As the trend in the development of the methodology is towards endpoints and corresponding safeguard subjects, effort is made to aggregate damages to them. For the EKF this aspect is not standing in the center. Therefore the earlier method EcoIndicator 95 is applied, specifically because its categories are known in applied research and industrial development. But there are some points to discuss. The newer definition of impact categories (SETAC 1999) opens options that are not available in earlier methods. The new impact category biotic resources, with subcategories water use, land use and biodiversity, is of challenging importance in the case of crop growing. These subcategories are not covered in earlier LCA methods (CML, EcoIndicator 95, 99) as presented for cotton growing in Tobler and Schaerer (2002). EKF integrates water consumption but not land use or biodiversity. Exergy effects, another subcategory (Finnveden 1998), are not modeled with EKF.

The weighting factors as discussed in Section 4.5.3 are limited to European values. The UNCTAD database (UNCTAD 2004) would provide additional data covering spatial LCA aspects. On the other hand, the number of impact categories with UNCTAD is drastically reduced, compared to LCA methodology, including coarse and overlapping environmental impacts, based on internationally negotiated agreements.

Ecological key figures represent a strongly simplified LCA as a life cycle perspective of textile goods. They set framework conditions primarily according to textile technology and thereby include the main variations in product and process technology. Required parameters for quality and environmental impacts are typical for textile processing and generally available. The calculated formula for the individual steps is based mainly on inventory data with only a few weighting factors to balance different impacts. These weighting factors are set according to ISO 14042. The model

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Table 4.27 Comparison of impact categories of different LCA methods and UNCTAD eco-efficiency

EKF	CML 92	E 95	Impact 2000	UNCTAD criteria
Fossil energy	Energy, greenhouse effect	Greenhouse effect	Extraction of abiotic resources, climate change	Energy, GWP[1]
Electrical energy	Energy, greenhouse effect	Greenhouse effect	Climate change	Energy
Water			Extraction of abiotic resources	Water
Land use			Land use, biodiversity	
Toxicity	Ecotoxicity	Ecotoxicity	Ecotoxicity	
Pesticides	Ecotoxicity	Pesticides	Ecotoxicity	
Agrochemicals	Ecotoxicity	Ecotoxicity	Ecotoxicity	
Fertilizer	Eutrophication	Eutrophication	Nitrification	
COD	Eutrophication	Eutrophication	Nitrification	Water
AOX	Ozone depletion	Ozone depletion	Stratospheric ozone depletion	ODP[2]
VOC	Summer smog	Summer smog	Photooxidant formation	
TKN	Eutrophication	Eutrophication	Nitrification	
$P_{tot.}$	Eutrophication	Eutrophication	Nitrification	
pHI	Acidification	Acidification	Acidification	
Heavy metals	Ecotoxicity, human toxicity	Heavy metals		
Waste		Solid waste	Human toxicity	
Transportation	Energy, greenhouse effect	Greenhouse effect		

[1] Global Warming Potential (with reference to the Kyoto protocol).
[2] Ozone Depletion Potential (with reference to the Montreal protocol).

of ecological key figures may be applied for other goods like food, ore refining, etc.

LCA models a more detailed system with individual parameters applied for a specific product line, whereby allocation is extremely complex. Consequently the detailed data collection hardly allows an accurate inventory and the chosen product line might be unrepresentative of the company's production processes.

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4.11.5 Adequate communication: B2B and B2C?

As strongly recommended by the EU Commission (Kommission der Europäischen Gemeinschaft 2003), electronic communication will be essential for a sustainable textile industry in the EU. Due to its simplicity in data collection the EKF is best suited for B2B as well as B2C communication. The formulas can be used in the detailed form (for each step in the value-added chain) or, if necessary for confidentiality reasons, in their aggregated form.

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5
Product development and marketing: management and communication

Abstract: This chapter shows how the marketing forces are imposing decisions on the textile value-added chain for economic reasons and thereby are setting the consequences for a sustainable development. The push strategy coming from the value-added chain has almost disappeared in favor of a pull strategy from product development and marketing, establishing new rules by working in a global environment. Comparisons are drawn between the American perspectives of the large merchants and the EU and Swiss economic structure with small and medium-sized companies, also including consumer behavior in the textile markets.

Key words: textile marketing, textile sourcing, textile consumption, ecological textiles, textile product placement.

This chapter provides basic information

- for all newcomers in the global textile marketing business with specific interest in Europe and America
- for textiles supply chain managers, who wish to improve their access to the market and their partnership with retail, thanks to a better understanding of marketing processes
- for consumers who want to learn more about textile marketing processes and reflect on their own consumer behavior.

5.1 Introduction

Product development and marketing of textiles and apparel take outstanding positions in the value-added chain. Here decisions are taken towards the markets, based on economic considerations, combined with available textile knowledge. Textiles are considered a soft good, compared to hard goods like computers, electronics and freezers, among others. Economic life cycles of textiles, particularly of apparel, and to a certain extent also of home textiles, are very short. Products have not only to meet the consumer's individual needs but also to provide a lifestyle by appropriate placement and promotion. Marketing of apparel, and to a lesser extent also of home textiles, requires closest contact with ever-changing consumer preferences. Consequently, a fine interaction with product development is a key issue for success.

This chapter presents marketing aspects one has to consider, and areas

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where marketing decisions take place. In Section 5.2 the historical development of the textile industry and structure is documented. Section 5.3 presents an overview on the 'Marketing environment', of which the main aspects will be outlined in the following sections. 'Global trade' (Section 5.4) is more than ever important for marketing of textiles and apparel. A special focus is set on the 'Consumer preferences' (Section 5.5) representing consumers' perception of textile products, whereas Section 5.8, 'Product development and merchandising', gives insight into the processes of creation and merchandising of textile products. The marketing perspective, including all relevant areas that apparel manufacturers and merchants have to cover, is presented in several sections. Section 5.6, 'Positioning', addresses the mapping of companies in a highly competitive environment. In 'Market segments and brands' (Section 5.7) relevant strategic decisions for the textile area are explained. Product placement, product positioning and advertising strategy are addressed specifically from the perspective 'Distribution and distribution channels' (Section 5.9), while 'Sourcing' deals with questions of domestic production and outsourcing (Section 5.10). Many areas include overlapping objectives.

There are countless publications available for marketing theories. This chapter is also based on case studies, carried out in the USA and Europe, to give evidence from practical experience. Two surveys have been carried out, in Europe (Engels and Hoerger 2001) and in the USA (Tobler 2003), investigating marketing aspects of textile companies on both continents. The European companies involved are AKRIS (a Swiss designer), Seidensticker (a German apparel manufacturer), ESPRIT (a global retailer) and two Swiss wholesalers (Migros and Coop). The American companies involved are Unifi (a yarn manufacturer), Burlington (an integrated company for weaving and finishing), VF Corporation, Sara Lee and Wrangler (apparel manufacturers), and Cotton, Inc. (consulting and promotion organization).

5.2 The structure of the textile and apparel sector

The textile and apparel business has developed its own rules on growth and decline, as will be addressed in this section. The general stages an industry runs through are influenced by historical political systems and other forces, which lead to different expressions of the market in different areas of the world.

5.2.1 Structure of the sector

Textile products can be divided into four main categories: apparel, home textiles, automotive and technical textiles. Each market has its specific marketing environment.

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The most frequent changes occur in *apparel* as they follow fashion trends. Accordingly their supply chain varies the most and may require partnerships with different suppliers. The gap between fashion shows and consumers' expectations has to be filled successfully. Textile suppliers (fiber producers, spinners, weavers and finishers) have to be as flexible as possible. Mainly in Europe, orders are getting smaller as a consequence of individualized fashion in a stagnating market. It becomes more and more challenging for a supplier to maintain profitability, because their business used to be based on high productivity.

Home textiles nowadays are very close to fashion because people tend to 'cocoon' themselves in their homes (Popcorn and Marigold 2001). Home textiles became an area of individual expression with a trend to seasonal cycles. The supply chain is somewhat less complex than in apparel. Fiber resources are often provided by monopolists (for man-made fibers), giving them a strong market position. In times of declining economy the home textile market follows such signals faster than in the apparel market.

The *automotive sector* shows some similarities with home textiles, but has to meet highest quality requirements. Additionally, certain fabric properties like suitability for recycling, no fogging effect of finishing, etc., require a high degree of innovation and process control. Orders include large quantities of fabric in a highly competitive market. For automotive textiles, fluctuation in the market demand is certainly a thread.

For industrialized countries *technical textiles* are the most promising category, subdivided into many applications such as medical textiles, geotextiles, sports and safety equipment, etc. (see Chapter 3). Competition within the industrialized world will take place mainly in this sector of the unsaturated market. Because of the high-value products and the growing market (Morris 2006) also growing economies like Thailand are forcing market penetration. Production of technical textiles requires specific partnerships with customers and suppliers mainly in terms of function and properties, including intensive testing. Prices and costs of such fabrics are high. There are many opportunities for niche markets of smart products. Marketing must include communication of high quality standards towards highly specialized retailers and consumers.

Long-term marketing strategies are more important than short-term profit. Technical textiles are particularly demanding in this area. They might be in a similar marketing position to cellphones and digital cameras, considered as hard goods, although their life cycles decrease steadily as they are more and more considered fashion goods. Emerging economies are fast catching up in their competence in technical textiles.

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5.2.2 Historical clusters of textile and apparel companies

Historically, textile mills settled in industrialized regions of the world with access to energy and water. Proximity to specific domestic textile fibers was another prerequisite. Unlike textile production, apparel manufacturing is mainly based on a skilled workforce, and therefore independent of large supplies of primary sources of energy and water.

Europe

Textile manufacturing developed in Europe in the Middle Ages and moved towards industrial production in the nineteenth century. These changes were caused by the new fiber material (cotton) and the development of automated textile machinery. They brought to an end a hitherto successful home industry of linen, silk and wool manufacturing. In the new era textile machinery became a driving force for the textile sector.

Centers for textile machinery first emerged in the eighteenth century and grew in the UK, the first textile center of the world for what was then the British Empire. The 'spinning jenny' and the 'power loom' were British innovations in the textile area. Also in Central European nations like Switzerland, Germany, Austria and Italy, textile machinery was produced and refined towards the end of the nineteenth century. Companies like Rieter, Truetschler, Suessen, Sulzer and Saurer developed textile machinery that is still in operation throughout the world. In spite of high protectionism in the UK, America developed its own textile machinery, helped along by industrial spying. By 1812 the USA, in those days a developing economy, had become sufficiently competent in the manufacture and use of textile machinery for mass production to be independent of the UK.

Textile manufacture settled in the neighborhood of technology supply. Global activities in importing of cotton and exporting textiles were carried out by the UK. In 1900 the UK accounted for 70% of worldwide textile trade. Losses in the US market were compensated for successfully by gains in the Asian market, where no industrialization took place. France was a strong supplier of linen products up to the beginning of the twentieth century, when it failed to develop modern industrial machinery. Increased imports of cotton shifted the fiber base for apparel dramatically (see Chapter 2).

At the beginning of the twentieth century apparel companies had their suppliers nearby, as the industry had grown in clusters. In Europe we still find regions for specific products, mainly fabrics: Italy has its cotton region around Lago d'Iseo, the silk region's center is in Como, and woolen fabrics are produced near Biella. Famous embroidery and laces are produced in Belgium, near St Gallen in Switzerland and in other regions around Lake Constance, including Austria (Vorarlberg) and Germany. Germany has its

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specialized knitting mills 'auf der Alb', a hill area near Rottweil, while Swiss spinning mills for fine yarns are located in the cantons Zürich and Glarus. Facilitated by the close neighborhood of small countries, sourcing frequently crossed the borders of those countries, which later formed the EU. Belgium has a high concentration of small knitting and weaving mills, including the carpet industry. The concentration in the central parts of Europe was further favored by the textile machinery industry being located in Germany, Switzerland and northern Italy. France has lost most of its textile industry, as it had specialized in linen but could not compete with its outdated linen textile technology against cotton imports. The UK, once a leader in fine woolen and cotton fabrics, underwent dramatic changes due to economic circumstances and lack of further development in textile technology. The Nordic countries never developed specialized centers for textile production, but developed considerable apparel production.

The historical development of the textile industry in Europe took place in a framework of ever-changing national borders. Most textile companies are still family-owned SME, sometimes with plants in different places. They developed fabrics for different European markets (see also Section 5.3). Due to this geographically small environment, labor unions are nationally organized, with strong forces particularly in the UK and Germany, and earlier in France. Up to the middle of nineteenth century, child labour was usual.

Today France is still one of the main designer centers (*haute couture*) in Europe. Italy is another focus for design, and the country also possesses a strong force in knits and textile machinery. Germany produces the largest amount of apparel, home textiles and technical textiles in Europe and is the main home of the textile machinery industry. Switzerland specializes in precision machinery, including textile machinery, and has niche markets for luxury fabrics (e.g. lace), high quality yarns and technical textiles.

In economic terms, Europe developed a mature textile industry long before the USA. The industry of a region or a country passes through succeeding stages as shown in Table 5.1. When starting allocation activities in a foreign region, it is only a question of time before this region builds up its own industry. When textile machinery manufacturing emerged, the young US nation had just started to build its new economy.

USA

The more the US became independent from the British Empire, the more it developed its own supply of goods, one of the first being textiles. The British kept their technical textile innovations confidential in order to foster the dependence of their new colony in America. Cotton as a raw material growing wild became the basis for textiles. The productivity in cotton processing was much increased by the invention of Eli Whitney's gin.

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Table 5.1 Stages of industry development

Stage	Explanation of development
Embryonic	Manufacturing of simple products for domestic market
Early exports	Simple products are exported
More advanced	Good quality standards in production, start of foreign investments
Golden age	Highly developed and industrialized manufacturing
Maturity	Product development and productivity in manufacturing on highest level
Significant decline	Only some key factors produced nationally, product development, high technology, niche markets

Source: after Vernon in Dickerson (1994)

Cotton was grown in the southern colonies with the help of slavery at the beginning, while production of finished goods was located in the north, a division still persisting today. The clothes manufactured in the eighteenth and nineteenth centuries had to meet the needs of people working mainly as farmers and craftsmen. Early mechanization was achieved by Samuel Slater who constructed a mechanized power loom from his memory of the British industry (Cassil 2003). The first stage in apparel production was a cottage industry including numerous small enterprises until the invention of the sewing machine in 1840 changed the structure towards industrial apparel production. In the nineteenth century a textile and apparel industry was developed employing men in textile production and women in sewing apparel. It is reported that also children worked in US textile factories (Trattner 1970). Many of the mill locations where the workers had their houses and shops became new towns in the expanding nation. Working conditions were hard. In 1911 unions of ladies' garment manufacturers claimed higher wages and shorter working hours. Up to 1935, when unions were legalized, an era of strikes powered by the illegal unions shaped the apparel business in the US. Ever since then, strong lobbying for the employees by UNITE has protected the textile and apparel business.

Innovations in the supply chain during the second half of the twentieth century gave power to different sectors within the supply chains. After World War II the allocation of textile and apparel production became more and more global, involving new countries in Asia, South America and Africa. These countries went all through the different stages from manufacturing of simple goods for a domestic market (embryonic) up to enforced exports based on a well-developed industry with a good, cheap labor force and (foreign) investments (see Table 5.1). After World War II tremendous fiber innovation in both North America and Europe continents gave the push for product development towards man-made fibers in the 1950s. In the 1960s

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the mills adapted the new fibers to their systems, providing innovative yarns and fabrics. Later in the century product development was shifted to apparel manufacturing and finally to designers in retail. According to new marketing strategies in the 1990s the 'pull' moved towards the customers, where it is still today. However, some companies in the supply chain are still successful in performing a 'push' strategy, providing the market with their yarn and fabric innovations.

In the US, textile production is concentrated in the east all along Interstate 85 from Georgia to Virginia with large centers in North Carolina. Apparel production moved to the southern US when in the 1970s wages became a critical factor. The next step in order to cut prices was to allocate labor-intensive work to countries with lower wages. Today 95% of all apparel is produced outside the US, mainly in Korea, Thailand, the Philippines, Vietnam, Malaysia and some countries in Central America. Still 30% of the fabric for apparel is produced in the US.[1] Some countries developed very fast by establishing a stable political system with open markets; others developed very slowly or even failed because of corruption and worked as trade barriers (see Section 5.4 on global trade).

5.3 The marketing environment of textiles and apparel

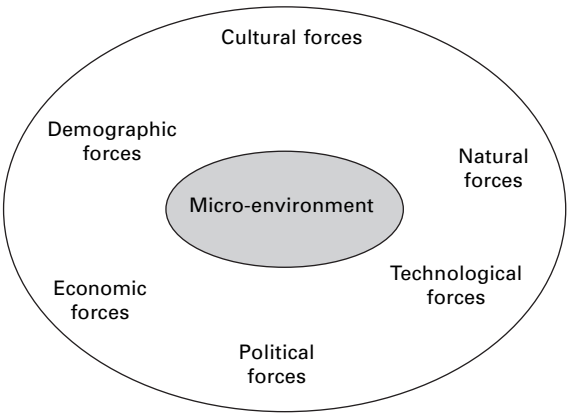
As in any other business, the macro-environment of textiles is determined by a set of main driving forces. In textiles and apparel the focus is on six aspects. Political and economic forces set primary conditions for the textile business, along with technical and natural forces (see Fig. 5.1).

Every nation, as poor as its economy may be, has developed a market for apparel based on individual cultural and demographic forces. In earlier times particularly natural forces led to the formation of an industry. With today's global trade this competitive factor has lost its stringency; this is the subject of Section 5.4. Today the development of a textile and apparel industry depends more on the technological, economic and political forces. This macro-environment will be addressed in this section.

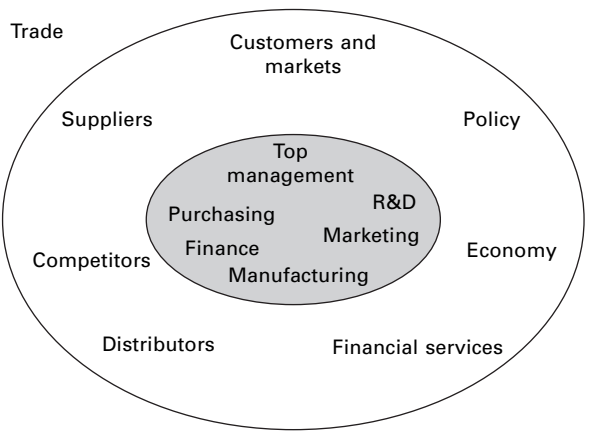
The individual marketing environment of a company is determined by its micro-environment, particularly by politics, economics and financial services. Each company has to establish an individual network of suppliers and distributors in order to be competitive in the market (see Fig. 5.2). The management has to take care for an appropriate financing for purchasing and manufacturing. Its marketing department has to follow the macro-environment in order to gain market shares as shown in Section 5.6. Research and development follow the requirement of the markets, as closely as possible

[1]Presentation to industry panel, Greensboro, NC, 8 September 2003.

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5.1 The macro-environment of a company includes all relevant forces to consider for the marketing environment.



5.2 The micro-environment consists of all the specific factors in the competitive environment of the company. Here the company's customers and markets are situated together with the competitors. Partnerships with suppliers, distributors and financial services have to be maintained in a hopefully beneficial environment of politics and economics.

to consumer behavior. The relation to the consumer is studied in Section 5.5 of this chapter; product development is dealt with in Section 5.8.

5.3.1 Politics

Whereas in Chapter 1 political forces were investigated in terms of sustainable development, this section deals with politics as a marketing factor. It will focus on the European Union and the United States.

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The United States consists of 51 states embodied in one nation with one democratic political system. The European Union represents 27 individual European nations, each of them having its own political system.

Although the United States of America are often taken as synonymous with America, we should not forget that the continent of America is divided into North America (USA, Canada and Mexico), Central America and South America. From an economic point of view, the USA can be considered as antagonistic to the European Union.

Like all nations practicing market capitalism, both the US government and the European Parliament promote competition and protect consumers. However, some European nations like the Nordic countries show some tendencies towards a centrally planned capitalism.[2] Additionally, restrictions on industrial activities are imposed by environmental and labor regulations to protect the countries' natural resources and the human rights[3] of its population.

Together with some of the main global economic players, namely Canada, Germany, France, Italy, Japan, the UK and Russia, the USA form an economic cooperation fostering political cooperation. Both the USA and the EU are members of the World Trade Organization (WTO), together with 144 more nations, many of them developing countries. This allocation in the WTO could benefit issues arising from developing countries, and give them the opportunity to correct some of the inequity caused by colonialism.

Politically the US administration alternates between two parties, the Republicans and the Democrats. While earlier Republicans claimed free trade as a driving force against Democrats, who worked more for protectionism, the positions have changed. Republicans still support free, but also fair, trade,[4] while Democrats moved towards free trade, some including the idea of global improvements in social and environmental issues.

The EU, led by the European Parliament, strongly supports the idea of free trade with a strong correlation to global improvements of environmental and social concern. However, one issue is still a big problem, that of agricultural subsidies which are supported by the US and fought by both developing countries and the European Union. It will be difficult for the US to claim a free but fair trade for textiles and apparel and stick to subsidies in their own agriculture, namely cotton. Another important change due in 2005 was the foundation of the Free Trade Area of the Americas, representing then the greatest trade bloc of the world. However, there are also opponents within the 34 countries to be included, founded on possible threads or opportunities for

[2]The economic rating of Finland's industry indicates no disadvantages caused by centrally planned capitalism.
[3]See WTO in trade.
[4]Here often the currency balance is addressed as an obstacle, but behind this might also stand protectionism of a less efficient domestic industry.

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their companies. Some countries in Central America can no longer produce for their domestic markets as their economy suffers from cheap imported goods.

It was interesting to follow the consequences of these two major changes in international trade by 2005, when developing countries and the USA fought for protection of their national economies. Since 2006 the 'Doha round' struggles in its negotiations due to insurmountable differences concerning subsidies, mainly between the USA and developing countries.

International relations

The US and every single European nation are individual members of the United Nations Organization (UNO)[5], with the aim of achieving and maintaining world peace. In this organization the European countries as individual members are free to choose and do not necessarily seek for consensus within the EU. The North Atlantic Treaty Organization (NATO)[6] consisting of the US, Canada and most of the European nations as members, coordinates actions worldwide to stabilize nations. However, recent actions of the US government have at times been more intense and aggressive, such as the war in Iraq, than actions originating from Europe. Here again, individual countries within the EU may or may not participate in worldwide activities according to national decisions. In many ways and in some of their political statements, the US consider themselves as the one country representing the free world, which might be a very limited point of view. Having contributed to ending World War II, the US consider themselves as a nation recognized worldwide as 'peacemaker'. Even if their political orientation towards world peace sometimes shows disagreements, the political relationship of the two hemispheres can be considered as a well-established partnership.

5.3.2 Demographics and cultural forces

USA

US citizens born between 1946 and 1964 form the so-called 'baby boomers'. Having gone through an earlier sexual revolution, most of them belong to upper segments that have been called DINKs,[7] WOOFs[8] and 'Grumpies'. They are in their fifties and sixties and care for healthy food, physical fitness, quality cars, convenience products and travel services. Today they represent 30% of the population with 50% of the income.

[5]http://www.un.org/english/
[6]http;//www.nato.int/
[7]'Double Income No kids'.
[8]'Well Off Older Folks'.

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'Generation X', born between 1965 and 1976, shows higher divorce rates, higher employment rates of women, more 'key-kids' and higher rates of AIDS. Due to increased financial pressure, they are more value oriented, caring more for the environment, society, better quality of life, bigger job satisfaction than career, and use of the Internet. They are now the greatest market force.

The 'echo boomers', born between 1977 and 1994, are still developing their preferences and behavior. They have much experience of children's and teens' markets with special toys, clothes, furniture and food, and are surrounded by digital technology.

Trends in family life show a higher age for motherhood because more women work for a career. Single households have become more numerous (one in eight family households). Many US citizens are heavily overweight.

Education of US citizens improved considerably from 1984 to 1996 (see Table 5.2). Among ethnic populations, Hispanics show the highest growth rate, becoming a big minority with 12% of the population (38.8 million citizens), compared to white (72%) and black (13%) ethnics.

There are considerable differences in shopping habits among the ethnic groups in the US. Only recently has the 'Latina' become a target consumer, as 71% of Latin American females claim to enjoy shopping (compared to 51% of Caucasian women). Hispanic females on everage shop 2.38 times per month for more than 2 hours and they are willing to pay a higher price.[9] Advertising with 'latin' models has helped to increase consumption by this ethnic group.

Europe

Europe often copies US behavior with a time lag of a few years. However, the demographic development is not as harmonized as within the USA. In the 27 member states of the European Union 22 different languages are spoken, which contributes to very heterogeneous demographics. Northern

Table 5.2 Education in the USA

1984	1996	
69%	82%	High school completed
17%	24%	College completed
1950	1985	
41%	54%	White collar
47%	33%	Blue collar
12%	14%	Service workers

[9]Cotton, Inc., personal communication.

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countries, on the one hand, may be more advanced in the expression of sexual revolution and have established a highly developed social economy which harmonizes the influence of the individual incomes. Motherhood is promoted by the government by means of birth leave for mother and/or father. The political system allows cheap access to cultural and sporting events. Southern and Mediterranean countries still maintain strong family bonds, often with several generations living in one place. Children are highly valued in society and often spoiled, even if their parents are not wealthy. Consequently the percentage of income spent on apparel is much higher. The percentage of people with higher education is lower than in Central, Northern or Eastern Europe.

The new Eastern European members of the European Union have gone through a long period of communism with no access to free markets but with a highly developed social system compared to the poorer national economies. Women from East European countries had always been working besides family life. They had better access to 'typical' male professions than in the rest of Europe.

In most European nations higher education is not correlated with higher income of the child's parents, as many nations maintain an education system paid for by taxpayers. The educational system in most European nations is a dual one, with one line including primary and secondary school (typically nine years), high school and university, and another line with primary and secondary school followed by an apprenticeship of three to four years (see example Switzerland in Table 5.3). Most European nations have negotiated the initiative of the 'Bologna process' in order to harmonize quality standards of academic degrees in tertiary education.

The shopping environment becomes more important towards southern countries. The buying atmosphere is an important shopping factor: luxury or cozily furnished shops, friendly personnel with individual service, and careful wrapping of purchases make shopping a unique experience, whereby the purchased good does not necessarily stand in the center of the action. EU consumers are used to seeing different ethnic models on the catwalk. Supermarkets provide the daily necessities, while visiting shopping centers is becoming a more and more important leisure activity. However, opening hours are limited to daytime, depending on the climate. In southern countries

Table 5.3 Percent of Swiss citizens in the four education sectors, 2004

Education sector	Percentage
Primary school	61.2
Secondary school	23.6
Higher education (college)	3.1
University	12.1

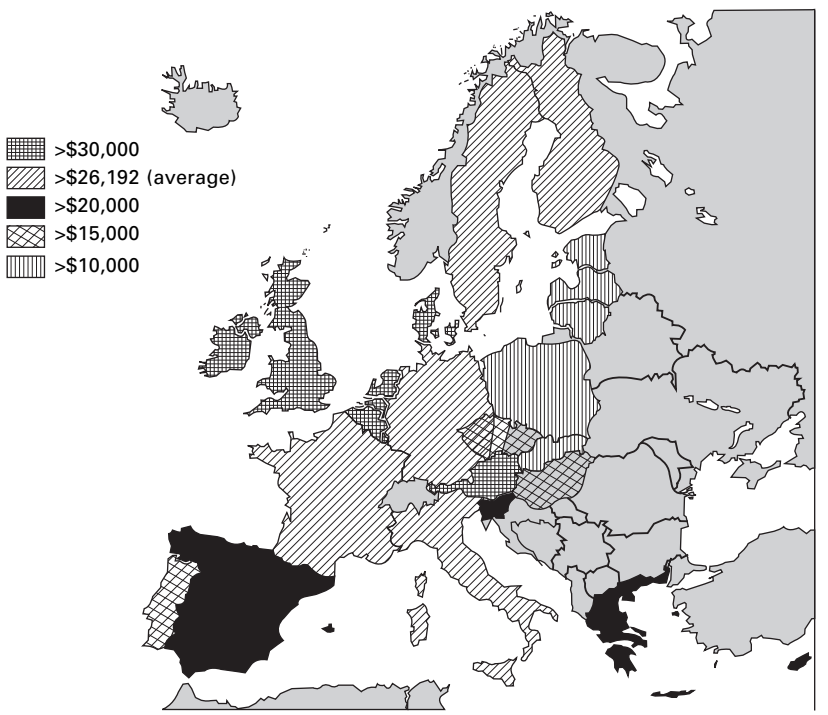
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most specialty shops are closed for a period in the middle of the day.

The European market is very heterogeneous, based on the different nations' economics. West European nations show higher purchasing power than those in Eastern Europe (see Fig. 5.3). The European market must also be considered as a cluster of different ethnocentric markets, according to the different cultures of customers, such as the Mediterranean (including Italy, Spain and Portugal) and Western Europe (French) both contributing to a high-context culture, with Central Europe (German-speaking countries), the Nordic countries (Scandinavia), the UK and Eastern Europe forming a more low-context culture. In high-context cultures less information is contained in the verbal part than in the context of communication (like associations and basic values).

Labeling culture

The only mandatory information for European apparel is type and percentage of the fiber content. However, most apparel also has a standardized care label with information concerning washing temperature, bleaching, dry cleaning, ironing temperature and tumble-drying. The US requires labeling not only



5.3 Buying power of European countries.

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with information about fiber content, but also with country of origin and manufacture as well as care and flammability. Sizes are labeled as well, but are different in Europe and the USA. Brands as a labeling activity of retailers are described separately in Section 5.5.5 from the consumer's viewpoint and in Section 5.7.3 from the marketing perspective.

The environmental performance of textile goods is recognized differently in the two continents (Boura 2002) (see also environmental labeling in Chapter 1) and can be expressed through the 'ecological footprint' (EF) (WWF 2002) of nations. The EF is measured in m^2, representing land use, product and services and sinks for waste. A global ranking has been calculated with the equation:

$$T = EF/GDP$$

The ranking is an indicator for sustainable performance and is based on the relation between environmental impacts and capital for damage repair. York *et al*. (2004) made this calculation for 139 nations, with the following ranking: Switzerland (1), Mauritius (2), Italy (3), Austria (4), Japan (5), Germany (6), France (11), UK (15), USA (33), China (76) and many African countries with ranking 120 to 139.

5.3.3 Natural resources

The USA has a large capacity for fiber production from natural resources. The country is still one of the largest cotton producers in the world, due to early mechanization of tillage and harvest processes (Day 1967). Ever since then they have benefited from an excellent pricing information system (Misra 1999). The USA disposes of a large production of man-made fibers, based on crude oil fractions. For more details on fiber production see Chapter 2.

Europe lost its natural fiber source when linen and wool became less important through the import of cotton, beginning in 1820. The prospering production of man-made fibers after World War II was lost to the Asian competitors, who built up capacity in high volumes. Europe and the USA built up excellent conditions for electric power generation, of which Europe copes with a lower consumption per capita. Large reservoirs of fresh water are situated in the Alpine part of Europe for power generation and process water: this is the traditional home of the textile industry, whereas flatter countries closer to the sea have scarcer capacity of fresh water. Power generation is also based on non-renewable resources and nuclear power. The US textile industry is based along the east coast of the continent and has settled along rivers. In this densely populated region energy and water have become a scarce resource due to high consumption per capita.

Power generation from different primary sources is associated with different environmental impacts (see Chapter 4) and may become expensive

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if environmental emission limits and controls are implemented according to the Kyoto Protocol of 1997.[10] In particular, finishing processes depend on high-quality fresh water. UNCTAD have defined criteria for the sustainable use of primary energy sources and water[11] (see Fig. 1.9 in Chapter 1). With the forecast climate change, these resources may become a crucial factor in several parts of the world with scarce natural resources (Kappel 2002).

5.3.4 Technological forces

The development of innovative new machinery is a competitive advantage for the textile industry, together with skilled machinery engineers and textile researchers. Europe always held a strong position in the area of textile technology, while the USA could not keep up with the Old World. Although in the early years of the democracy some knowledge was built up, the technology drive was given up long ago (see Section 5.2). In Central Europe the development of technology is being pushed still further for domestic and international markets. After World War II Japan became a major player in textile technology. From a historical advantage of a high energy supply gained from hydropower and an experienced work force, Europe still has excellent conditions for a high innovation potential. However, Japan presents strong competition in many areas, whereas the other Asian countries are only beginning to develop comparable technological forces. However, in e-business the Asian countries may easily surpass traditional companies (Meyer 2001).

5.3.5 Economy

There are two perspectives for the economy of textiles: one from the consumer (the textile and apparel demand) and the other from the producer (textile and apparel production). In the first subsection below, the buying power for the market in the two areas is compared. Then some rules for scaling in textile production are presented, followed by case studies in two traditional 'textile regions', Switzerland and North Carolina, and in the growing textile region of China.

Buying power

In 2003 American households spent an average of $442 in a season ($513 for lower income), $15 more than in 2002[12]. In 2003 sales of apparel in the

[10] http://www.unido.org/doc/3941
[11] http://www.natural-resources.org/water/index.htm
[12] *Lifestyle Monitor*, fall issue, 2003.

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US expanded by 4.4% (in units) which is considered a moderate growth, though dollar sales declined by 0.4%. The largest growth (7.6%) was found in men's wear with a total apparel market share of 36%[13] and women's wear grew by 2.4% in a period when the consumer price index declined by 2.5% for men's apparel and 3% for women's respectively (compared to the previous year). As a result, the market for men's is stated at $95 billion and for women's at $153 billion. Mass merchants are still the main channel for purchasing and mail order still has a small market share.

Market research by Cotton, Inc. showed a growing share of cotton (based on fiber weight). Looking at individual products, denim apparel lost 1.9% and wrinkle-resistant apparel shrank by 9.2%, mainly caused by middle-aged women with middle-income purchasing in mass merchants. Purchase of knit shirts and tops increased twice as much as average apparel due to a preference of young customers for knits.

In Europe the buying power of €100 is specific for each European nation as Table 5.4 shows. Consequently prices for the same (textile) product cannot be equalized. Cultural preferences in expense for apparel determine the national buying force for apparel.

The textile industry is characterized by its considerable costs for energy for spinning and weaving. For finishing, high water and chemical consumption together with high energy demand is typical, while manufacturing is very labor intensive. The West European and US textile industries have lost enormous market shares. The remaining industry can survive only with highly automated

Table 5.4 Buying power (in €) per €100 of European nations

Slovakia	202
Czech Republic	201
Poland	186
Turkey	179
Portugal	123
Greece	115
Spain	115
France	108
Belgium	105
Italy	103
Germany	102
Netherlands	101
UK	88
Switzerland	78
Denmark	74

[13]Cotton Incorporated: Men's Apparel Market, 2002 Annual Report.

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processes of high productivity. The labor-intensive manufacturing has moved to a great extent to Asia, Eastern Europe and Central/South America.

Most US textile companies produce on large scales, while in European countries small and medium enterprises generate the predominant turnover in textiles. Table 5.5 gives ranges for small production lots (typically for European companies with decreasing market shares) and the economic size to be aimed at.

Minimal turnover for economic apparel manufacturing and merchandising is given in Table 5.6. The highly segmented markets in Europe lead to small-scale oriented manufacturing for production in Europe. US companies always operated with much higher turnover in their large-scale domestic markets.

Case studies

Three textile areas will be presented as case studies in this section. Two of them represent traditional textile regions: North Carolina in the US and Switzerland as a Central European country; the third is about China, a growing economy, particularly in textiles.

North Carolina

North Carolina's textile and apparel sector called for the largest employment with 166,734 persons in textile mills (number 1 ranking in North Carolina) and 46,355 workers in apparel, ranking seventh in US manufacturing employment (still 5% of the workforce) in 1998. The two other major export sectors are

Table 5.5 Minimum and economic turnover of companies in the value-added chain

	Small lot	Economic lot
Fibers	100 to 9999	10,000 upwards
Yarns	10 to 999	1000 upwards
Gray fabrics	1000–9999 kg	10,000 kg upwards
Finishing	100–999 kg	1000 kg upwards
Manufacturing (industrial)	10–99 kg	100 kg upwards

Table 5.6 Minimum and economic turnover of manufacturers

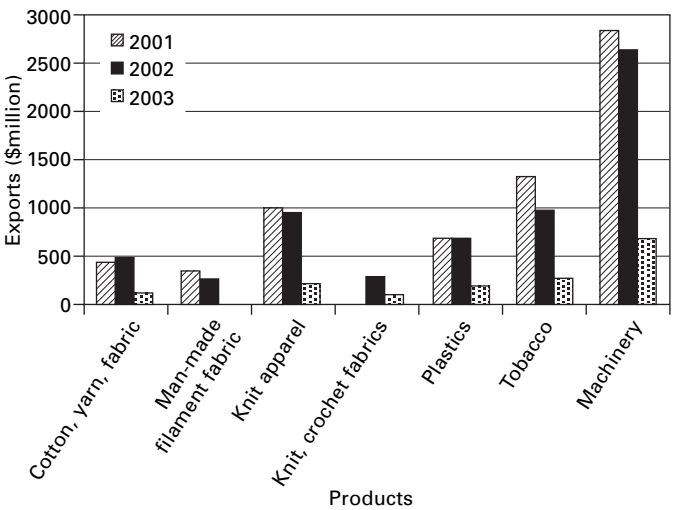
	Minimal ($)	Optimal ($)
Brand/distributor	100 million	1 billion
Product line	10 million	100 million
Article	1 million	10 million

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machinery and tobacco. Figure 5.4 shows the tremendous decline of the three sectors in the years 2001, 2002 and 2003.

Between 1988 and 1998 non-farm employment increased by 28%, compared to 20% US average. This shift was mainly caused by losses of farms and compensating investments by foreign companies from Germany and the UK, generating 4285 new jobs between 1988 and 1998. But these jobs were not for the benefit of textiles and apparel, where 90,000 jobs were lost in the same period (see Table 5.7) .

However, the two segments of textiles and apparel did not develop identically. Wages in textile mills (weekly average $502) are significantly higher than in apparel manufacturing (weekly average $378) as shown in Table 5.8. Textiles have been the major part for over 100 years, serving both domestic markets and exports. Apparel production lost shares of the domestic market and could not compensate with exports. As apparel production shifted to countries with lower wages the industry suffered important job losses. Many textile mills stayed in business as long as US retailers relied on US



5.4 Development of exports from North Carolina in million US dollars.

Table 5.7 Development of the textile work force and its earnings in North Carolina

	Textile mills		Apparel manufacturers	
	1988	1998	1988	1998
Employees	225,000	170,000	85,000	50,000
Earnings ($)	17,000	26,000	12,000	19,500

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yarn sourcing, although shifting from domestic markets to export markets. Job losses in textiles were partly due to the increased automation, driven by the requirement for higher productivity.

Textile mills in North Carolina have started specializing in innovative fabrics, mainly for automotive, technical textiles but also to a lesser extent in apparel, thus being involved in product development of retailers.

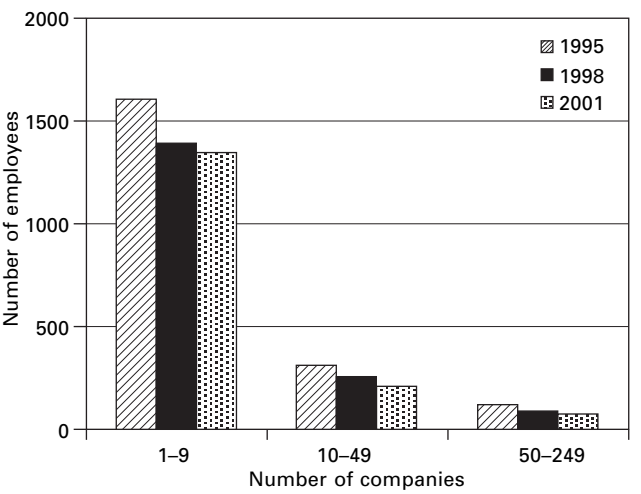
The Swiss case

The Swiss textile industry is built of typical SME, often family owned over generations. 1648 companies were active in the textile sector in 2001, including textiles and apparel, retail, laundry and dry cleaning. The majority were companies with 1–9 employees, thus the smallest size, operating in small niches (Fig. 5.5).

The main business partners of the Swiss textile industry have always been the member countries of the EU. Since 1990 the industry has suffered from

Table 5.8 Development of wages and working hours in North Carolina

	Textiles		Apparel	
	1988	1998	1988	1998
Average wages/hour ($)	12.6	12.57	9.73	9.47
Average wages/week ($)	504	502	389	378



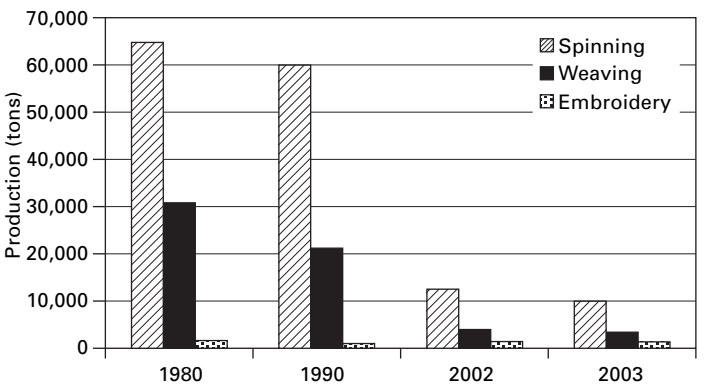
5.5 Size of Swiss textile companies (source: Bundesamt für Statistik).

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a marked decrease in volume (Fig. 5.6)[14], while the economic decline did not achieve the same magnitude. The production index was cited at 66% in 2003 (with reference to 100% in 1995), while the average economic index had climbed to 115% in the same year. The textile industry took the second-last rank in the Swiss economy.

The export index (in Swiss francs) of yarns and fabrics declined to 57% (2003) as Fig. 5.7(a) shows.[15] The production index of apparel went down to 71% and the export of apparel increased to 160%, a result achieved by addition of apparel merchandising and domestic production (see Figure 5.7(b)). The Swiss Textile Association estimates a reduction in the turnover of the Swiss textile and apparel industry of 6.1% between 2002 and 2003. A progression was caused in Western countries mainly by large imports of cheap merchandise from countries with lower wages and marginal environmental legislation. Only innovative companies survived, focusing on technical textiles and other high valued fabrics. Such specialization in new markets and niches required additional financial resources. Investments had to be made with a certain risk in new technologies to open new markets. Not all enterprises were successful. Particularly the traditional cotton sector was highly affected and only the best survived. Others were outsourced and became successful in East European or Asian countries.

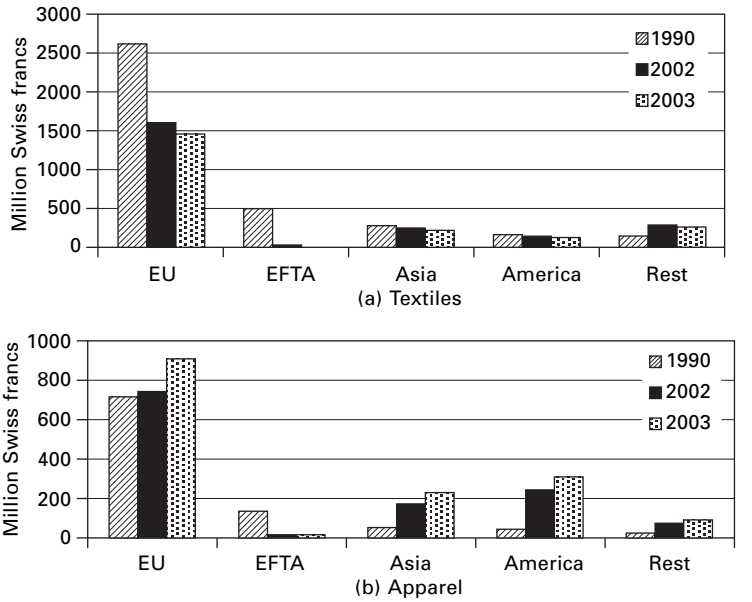
Considerable investments and costs were generated through the environmental legislation (BAFU 2005), which concerns mainly the finishing companies. Nevertheless, many companies have established voluntary environmental systems (ISO 14000 and Eco-Tex 1000) and environmental



5.6 Development of Swiss textile production (source: Swiss Textile Association).

[14]Data from statistics (Swiss Textile Association), tons (weaving) based on an average weight of 200 g/meter.
[15]Calculated from statistics (Swiss Textile Association).

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5.7 Development of Swiss exports of (a) textiles and (b) apparel (source: Swiss Textile Association).

labels type II (see Chapter 1). Some interesting and promising opportunities in cooperation have been developed by ETH Fallstudie (ETH-UNS Fallstudie 2002) for the textile sector of Appenzell canton and a study of the Swiss Textile Association, TVS, concerning the future of the Swiss textile industry (TVS/ETH 2003).

The China case from a US perspective

China consists of a work force of 7.7 million people in the textile sector. After 1970 the so-far centrally planned market opened to global trade. Today exports of $270.2 billion (textiles and toys) are balanced by $270 billion of imports (mainly machinery). The textile sector consists of 70,000 companies, of which only one-third has high manufacturing capacity, the rest being SMEs. China shows a 10% growth rate based on raw cotton and wool. This increase required additional workers in textile companies. They moved from rural areas to the textile towns and are often paid lower wages, with frequent reports of their human rights being adversely affected (Rivoli 2006).

Since 2001 China has been a member of the World Trade Organization (WTO). The country started to benefit from the trade liberalizations in 2005, when tariffs were phased out. There remain serious concerns about human rights and the equivalence towards Western currency. Some countries, such as the US and France, even imposed a limit on imports.

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As imports from China for specific textiles increased dramatically between 2000 and 2002 and prices eroded, US textile associations launched a petition to declare knits, dressing gowns, brassieres and gloves as safeguard subjects. The lobbying included 14 major textile associations: the National Textile Association (NTA), the American Textiles Manufacturers' Institute (ATMI), the American Apparel and Footwear Association (AAFA), the National Cotton Council (NCC), the American Yarn and Spinner Organization (AYSA), etc. The petition was sent to the Committee for the Implementation of Textile Agreements (CITA).

Cassil (2003) reported the closure of six knitting mills in North Carolina since January 2002, a decline of 52% in production. Meanwhile Pillowtex closed, leaving 6000 workers unemployed. Nationwide production declined from 83% to 76% of the domestic market share, combined with a price erosion from \$0.77 to \$0.37/m^2. In the same period, prices for dressing gowns declined from \$2.03 to \$1.13 (cotton) and from \$2.88 to \$1.64 (man-made fibers) per m^2. Imports from China increased from 4% up to 23%, while US production suffered a decline from 25% to 10%. Prices for brassieres as an added-value product, made of man-made fibers representing 85% of the market segment, declined from \$15.19 to \$7.04. The breakdown for gloves began in 1999 when production declined from 38% to 29% (www.atmi.org). However, in this period China did increase imports. Only after 2001 did they increase imports from 8% to 24%. By that time US production was down to 23%. This might be the reason why gloves were taken out of the safeguard subjects. The associations objected that China was not acting according to the WTO agreement. US textile associations also reminded the Bush administration of the promises given towards the Carolina textile industry in return for their votes. CITA, an inter-agency group of North Carolina's chamber of commerce, consisting of state, labor, treasury and trade department, was given 15 working days to ensure the correctness of the petition. Thereafter OTEXA would publish it during 30 days in order to receive comments.

5.4 Global trade

International trade in textiles is a tradition in the history of the textile industries. The natural resources and technologies developed in different countries of the world made silk, cotton and other fibers a desired merchandise. Competition was based on the availability of the raw material, the technology to make fabrics and access to global markets. Production technology was kept confidential and many countries protected their resources and knowledge by imposing bans on export (China for silk, India for cotton merchants, UK for textile machinery). With the availability of safe and fast transportation the relative competitive advantage for countries with no natural or technical resources

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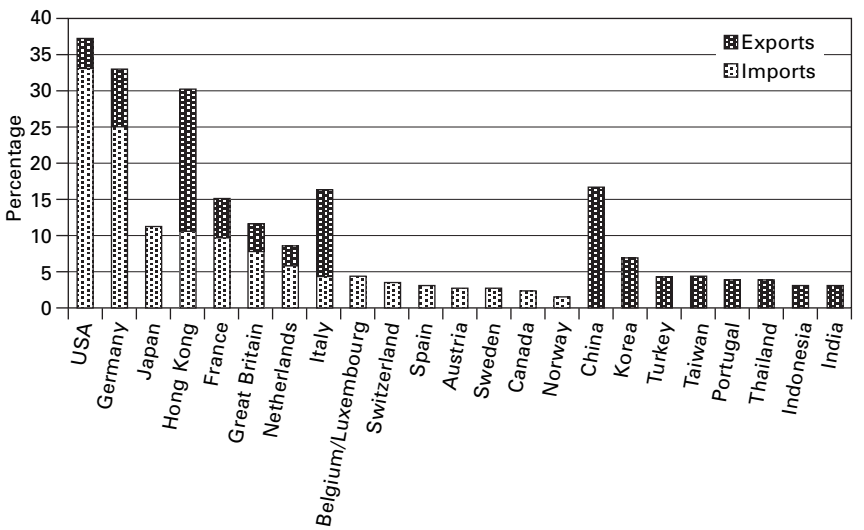
grew. Countries adjusted political framework conditions like tax reliefs for industry, and subsidies, and export facilities to access foreign markets. This resulted in changes of import/export volumes of different nations. Figure 5.8 gives global import and export figures for the textile sector.

5.4.1 Trade blocs

Trade blocs have developed in three parts of the world: Europe, America and Asia. Only the African continent seems to stay aside in this development and consequently lacks the economic benefit of such cluster formation. This section will characterize the two older blocs, Europe and America, in which imports and exports are concentrated (see Fig. 5.9).

European Union

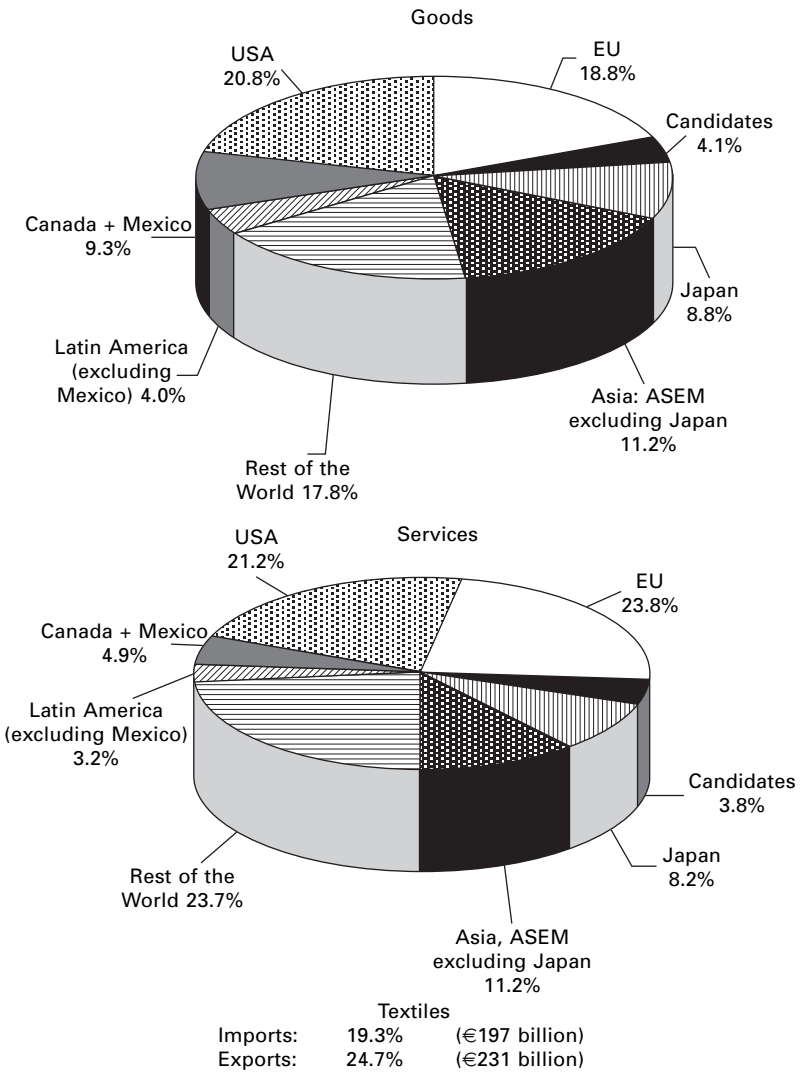
In 1947 a small group of European countries – Austria, Denmark, Norway, Portugal, Sweden, Switzerland and the United Kingdom, members of the Organization for European Economic Co-operation (OEEC) – founded the EFTA (European Free Trade Association). This was to implement the Marshall Plan for the economic recovery of war-shattered Europe and to promote economic cooperation between member countries.[16]



5.8 Imports and exports of textiles and apparel in 1992 (source: ILO 1996).

[16]http://secretariat.efta.int/Web/EFTAAtAGlance/history

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5.9 World trade in 2003 with import and export figures for textiles and apparel.

Winston Churchill's idea of a European cooperation in a common market, pronounced in 1946, is considered the starting point for the political integration. In 1958 six countries – Belgium, West Germany, France, Italy, Luxembourg and the Netherlands – negotiated the Treaty of Rome and founded the European Economic Community, later to become the European Union (EU).

Some of the EFTA members joined the EU in 1973 after several attempts for

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cooperation between EFTA and EEC. The majority of the European countries thereafter were integrated in the EU.[17] In a period of more than 40 years since its foundation, the European Union developed from a free trade area more towards a political union. By introducing common tariffs, a common currency (1991 Treaty of Maastricht) and a political system including the European Parliament,[18] the EU harmonized legislation among the member states. Since then, only a few countries of the European continent such as Switzerland and Norway have not become EU members, but are connected with bilateral agreements. The European Union has undergone great changes and grown considerably by the inclusion of the new member nations from Eastern Europe. Before the enlargement, EU 15 generated a turnover of 200 billion euros with 177,000 textile companies (mainly SME) and 2 million employees. The textile sector is important for the new members. Within EU 25 the work force in apparel and textiles grew to 2.5 million, representing 7% of the working population in the industrial production area.

The new members are known from the passive finishing trade: 75–90% of their textile merchandise was imported to EU 15 and 45–75% was exported from EU 15 to the new members.

There is a gradient in added value between EU 15 and the new members, where 10% of the added value was generated by 60% of the employees. The new members also lack experience in fashion design, which certainly represents a competitive disadvantage. Wages, on the other hand, will increase in the new member countries, due to competition from Asia. Additional funding is required for the implementation of environmental improvements to meet the guideline 96/61 EG.

Even though the EU has become the biggest trade bloc, there are additional trade relations with EFTA nations. Turkey becoming an EU member might be the next step of enlargement. The EU also holds trade relations with other Mediterranean neighbors (North African countries). This leads to the aim to create a Mediterranean free trade area, in which the proximity of and short distances between the nations will be a competitive advantage compared to the US and Japan, though it would still suffer high competition from China, India and Pakistan. Goals for the establishment of a Euro–Mediterranean free trade area are as folows:

- New cluster strategy to survive: broader geographic base
- New areas: technical/industrial textiles, non-woven (filters, hygiene fabrics, geo-textiles), automotive, medical textiles
- New markets: quality, design, innovation and technology, value-added production

[17]http://www.europa.eu.int/abc/history/index_de.htm
[18]http://www.europarl.eu.int/home/default_de.htm

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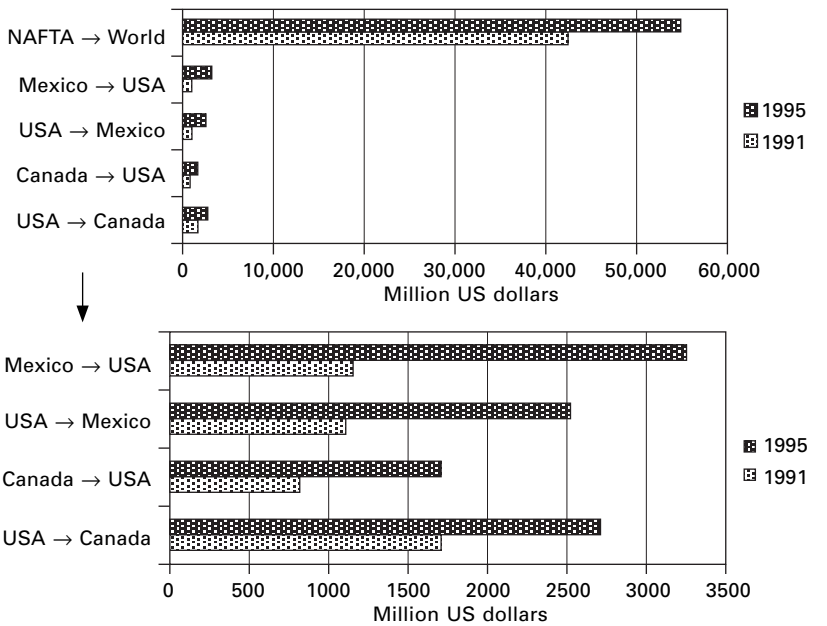
- Competition through sourcing in countries with low wages (South and East)
- Growth in fabrics with added value necessary
- Environmental standards (OECD, UNEP)
- Protection against dumping prices.

Further trade relations are being established with the Mercosur (Mercado Común del Sur) countries in South America. A crucial challenge will be the better protection of intellectual property against Asia, a difficult but critical task for the European industry.

The USA and trade blocs

The US negotiated the NAFTA[19] (North American Free Trade Agreement) with Canada and Mexico in 1995. Since then, economic cooperation between these countries has increased considerably (see Fig. 5.10).

A common market with the Central American Common Market (CACM) has been established. More recently, the orientation towards the Caribbean



5.10 Increases in apparel trade, due to the creation of the trade bloc NAFTA (source: North American Textile Council).

[19]http://www.citizen.org/trade/nafta/index.cfm

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nations, meeting the Caribbean Basin Initiative (CBI), has become more important.

5.4.2 Trade barriers

Global trade aims at entering new markets or sourcing in countries with competitive advantages. Such actions may only be taken if a stable and durable partnership is achieved (see Section 5.10). Political stability and free capital flows are the most prominent requirements. Even if the legal aspects of international trade and the specific merchandise are known, it might be difficult to communicate across cultures. Table 5.9 gives a list of aspects and possible barriers that have to be considered for operating in a global environment.

A consequent and inclusive cost calculation must be enforced, including wages, infrastructure and energy, taxes, fees, tariffs, shipment, licenses and all possible future costs. Cost reductions should never be the only reason for global trade. Proximity to the market in combination with shorter delivery times are very critical for textile markets and allow higher revenues.

Table 5.9 Possible barriers in international trade

International legislation	Trade quotas
	Taxes
	Product-related legislation (contract penalty)
Contracting and licensing	Intellectual property
Capital flows	Balance
	Stability of currency
Political stability	Democratic structures
	Peace/war
	Health issues (SARS)
Product quality (sourcing)	Worker skills (education)
	Reliability
Cultural differences	Corruption
	Language
	Adaptation of product segments
	Mutual acceptance
Fast-growing economies	Unemployment
	Working conditions
	Environmental, ecological and health impacts
	Waste management
Political global cooperation	Logistics → time to market
	Investments in education
	Social accountability
	Solutions for environmental problems

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When starting business in a foreign country it is highly recommended to cooperate with a confidential intermediate agency. The efforts for high quality production are often underestimated, because of an unskilled work force or poor communication. Maintenance of the technical equipment or energy supply may suddenly become difficult. Moreover, environmental problems can occur and require appropriate action in a poor infrastructure. Additional legal requirements may appear and call for unexpected investments. Copying is a well-known offense in Western legislation, but also an unavoidable consequence of production in Asian countries, because intellectual property is not protected there. The analyses of dynamics in cross-border trade and investments as well as on the proportion of companies' revenues generated in key world regions will support decision making for trade relations. Last but not least, one can learn from experiences of competitors in the textile business.

5.4.3 Textiles and apparel under GATT and WTO

Trade has always been an issue for people since the earliest times. In the early days it was barter trade; later a monetary equivalence was created to ease trade (Binswanger 1991). In history, textiles have been traded ever since the days of the 'silk road' from China to Europe or the shipping of cotton from the New World. Trade within the European nations was well developed at a very early stage and has intensified ever since. During the period of colonialism, the trade relations of Europe were expanded to many new places all over the world, including the North America. The US succeeded in gaining their independence from Great Britain, the mother country, focusing on a national economy. Only in the twentieth century did trade with other nations become more important for the USA. For historical reasons, Europe globalized its market earlier than the US.

Some countries protected their domestic markets by means of tariffs (taxes on imported goods) and quotas. The latter are restrictions on the amount of imported goods, compared to domestic consumption and production. As textiles and apparel is one of the first industries to be established in a country, such tariffs and quotas were about the first to be implemented. Because of the increasing trade activities in the twentieth century, the General agreement on Tariffs and Trade (GATT) was founded in 1948 in order to regulate trade and competition. The first exceptions for textiles and apparel, mainly cotton products, were agreed on in 1960 and 1962 with the Short Term Agreement (STA) posing a one-year restriction on 64 categories of cotton textiles. It was succeeded by the Long Term Agreement (LTA) limiting the annual growth of cotton imports to 5% in order to protect (US) cotton textile production. Under the LTA the US negotiated 18 bilateral agreements (Dickerson 1994). The US suffered from rapidly growing imports and forced the introduction

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of a series of four Multi Fiber Agreements (MFA) from 1974 until 1995:

- MFA I: 1974–1977: ceilings for total amount of square meters in SME group (e.g. sweaters) and category (e.g. man-made sweaters), ceilings increase 6% quota, 'swing', 'carry forward' and 'carryover' allowed
- MFA II: 1979–1981: call mechanism on products with sudden increase, exception to depart from 6% ceiling if market disrupted
- MFA III: 1981–1986: call reversed to anti-surge protection on most sensitive products proof of decline of per capita growth rate or per capita consumption
- MFA IV: 1986–1991: duties on imports of subsidized products, rules of origin introduced to avoid transshipment, unilateral restraints in case of bilateral disagreement, poorer countries favored, cotton and wool still protected.

Under MFA I the EU did not sign many bilateral agreements as it seemed difficult to find agreements upon distribution within the Union. Consequently the EU faced reduced trade barriers with transshipments from developing countries to developed countries and a corresponding market penetration of 49%. MFA II allowed for a call mechanism in cases of sudden increase of imports. As developing countries were restricted they became more organized and achieved MFA III, requiring proof of the claimed import growth. MFA IV was initiated by the US, suffering from a 200% increase of imports. In 1995 MFA IV was replaced by the Agreement on Textiles and Clothing (ATC) to phase out the MFA over 10 years.[20] In the same year the activities of GATT were moved to the World Trade Organization (WTO). Today more than 150 countries, including many developing countries, are WTO members, the US and the EU voting as one member each. Consequently the structure of membership gives the developing countries more votes. As many of their economies are in deep debt, partly caused by unfair competition against industrialized countries in earlier times, this may be a chance for them to become successful by altering the trade regulations.

The WTO agreement of 2005 eliminates quotas but still allows tariffs on imported goods. Competition in the market should take place in terms of costs. Some countries (the US and France) have already imposed economic sanctions because they feel threatened by booming imports.

If different national legislations are to be applied on merchandise, it becomes essential to meet all requirements for all fabrics, such as jurisdiction, intellectual property in production (including trademarks, unauthorized copying and specifically patents) and in publications, and to observe international treaties.

[20]For differentiation between retail and production, see also Section 5.10, Sourcing.

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Export of goods also includes meeting the environmental legislations concerning the goods. The EU and Japan introduced demanding requirements in environmental issues. For apparel, restrictions mainly focus on finishing agents like carcinogenic colors and auxiliaries. Technical and automotive textiles face additional requirements like waste management and recycling.

Sustainability of the textile and apparel trade

Free trade on the one hand will be a prerequisite for a sustainable world by improving economic, social and environmental conditions, even if there will be many disruptions by unbalanced economies. On the other hand, there will be significantly more transport in the race for best prices worldwide. The severe competition forces prices for textiles to decrease while prices in other industry sectors (in less mature markets) increase. Specifically in developed countries with higher wages the process cannot be considered as sustainable from an economic standpoint (Torres 2001). Moreover, textiles and apparel are becoming a disposable good and thereby creating a great environmental problem in the long term, especially in countries with landfills.

The perspective for a sustainable textile industry, launched by the EU, is valid not only for Europe and requires the follwing:

- Changes:
 - Partnership with employees and authorities
 - Public procurement
- Research:
 - Improve new processing
 - Intensify investments and research
 - Integrate research (universities–industry)
- Innovation:
 - Close gap between research and application
 - Increase information-management (B2B)
- Environment:
 - Reduce amount and load of waste water
 - Introduce life cycle perspective
 - Apply IPPC (96/61, 1996)
 - Integrated product policy
 - Encourage EMS, labeling
 - REACH registration of chemicals
- Intellectual property:
 - Harmonization of legislation.

Also the American industry would benefit in the long term if it would address the same goals, even if some environmental improvements may require a certain investment. And last but not least, the Asian continent will

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find itself sooner or later in a dangerous environmental trap, the result of a fast-growing economy.

Companies interested in sustainable trade have to answer the following questions and to seek solutions:

- How does sustainable development affect production, marketing and distribution?
- What tools for the implementation of sustainable management systems are available?
- How to develop strategies for sustainable product development?
- How to establish guidelines for communication with business partners and consumers?
- How to simplify the collection of scientific data of products and processes?
- How to evaluate the sustainability of products and labels?

For most of these questions there are answers in this book. From the marketing perspective there is one main reason to start immediately: the first-mover advantage in sustainable development.

5.5 Consumer preferences

The consumer's perspective describes his or her personal awareness of the market. It is the subject of countless market studies, performed by companies and associations. The main subjects are the 'value definition' and the perception of quality and services. Personal styles and preferences of material as well as desired care properties give signals to the marketing departments of companies.

5.5.1 How to define customer value

In (textile) marketing the value provided for the customer is defined by the following equation:

$$\text{Value} = \text{perceived benefit/price}$$

Price is the most reliable value within this formula for customers worldwide. For the US, market price is the most important factor, whereas Europeans are more value oriented as far as their economic situation allows for it. The perceived benefit includes many factors such as quality and style (including cut, color, size and fit), brand, services and care properties as well as the retailer's image and commitments. Perceived benefits are highly influenced by the customer's culture and as such differentiate essentially between the EU and the US. US customers set the following priorities in purchasing: first, price; second, fiber; third, laundering and care; fourth, brand; fifth,

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environmental issues. However, looking at young customers, brand becomes second priority (Keyes 2003). As color and fashion are eye-catching they are often not considered as a decision by the buyer. Cut, fit and size are tested before a buying decision is made. Generally the US textile and apparel market is strongly driven by price.

In European markets prices are also dominant, but perceived values generally play a more important role than in the US. European markets show characteristic differences in cultures, each of them having developed its inherent values. Cultures with high context require much more focus on value, not only of the product but also of the purchasing environment (see demographics and culture, Section 5.3.2).

5.5.2 Price

Even though textile prices in the US have declined in real terms year by year, only 56% of the population were willing to pay more for quality in 2003 compared to 64% in 1994 (Cotton, Inc. 2003). Preference for quality before a fashionable look decreased from 68% in 1998 to 62% in 2002. Reasons for the changes are found in so-called 'cross shopping': more than 80% of consumers shop at several retail channels for apparel.

A shift towards low-price apparel became evident between 1997 and 2003 when consumers increased their purchases at mass merchants by 4%, while shopping mainly in department stores, chains and specialty stores decreased by 8% (Cotton, Inc. 2003). In 2001 still 41% associated higher-priced apparel with longer lifetime and 45% believed higher prices were due to stylish apparel (average of all channels). These percentages fell to 34% (for longer lifetime) and 41% (more stylish) in only one year.

Most Europeans still associate higher prices with higher quality, as they assume such apparel is produced in Europe under standardized manufacturing conditions. Retailers adapt their prices to national economies, depending on buying power (Section 5.3.5). Consequently most nations have different markets. Such differences have increased cross-national shopping, further promoted by the short distances. Shopping in different countries not only has price advantages but also offers different products and cultural values.

5.5.3 Quality

The term quality is not clearly defined and may include aspects mentioned in other parts of this chapter.

Most US consumers are largely satisfied with the quality available in retail. This is a result of retailers' efforts to increase quality, even in mass merchants. The consumer's perception agrees that in the low-price segment

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quality is generally good.[21] More than two-thirds of customers throughout department stores, chain stores, specialty stores and mass merchants indicated their satisfaction with mark 7 and higher on a scale of 10.[22] However, nearly one-fifth of all returns to retailers are due to quality issues.[22] Analysis from a consumer platform (PlanetFeedback) showed that over 80% of comments about specific apparel retailers were complaints.

European consumers have high expectations in terms of quality. They understand quality as material properties but also as quality of cut and sewing. In the moderate and higher-priced segments added value in sophisticated cuts is often advertised with enhanced body shaping and fitting.

5.5.4 Style, including design, cut, color, size and fit

Style is a commonly used term for the definition of one's personal expression, achieved by apparel and fashion accessories, including trends in color and cut. Style and fashion have been developed for centuries in Europe.

The US cannot look back on such a long fashion tradition as Europe. In the early years of settlement women's apparel was produced at home while men's was tailor-made. Later, women's fashion was imported from Europe. Since 1880 New York has been considered as the fashion center of the US, where most of the local apparel production was made by immigrants (Frings 2002). But still in the early twentieth century, fashion was being imported from France. Fashion design became increasingly influenced by Hollywood. During World War II, the US was cut off from the influence of France and created women's working dresses. Only in the 1980s did US designers start to export. Since then the US has created its own style, led by designers located in the region of New York, but today also in Hong Kong. In recent years US designers have gained considerable market share in Europe.

However, some European influence is still prevalent. Particularly, the knit sector is influenced by Italian design and technology. Colors and styles for the US market are adapted to the target costumers and ethnic groups addressed.

In Europe centers for fashion shows are located in Paris, Florence, London and Düsseldorf, developing specific styles for a worldwide market of well-off consumers. According to its origin, apparel production represents the typical French, Italian, etc., style, offering a choice to customers.

An increasing proportion of US consumers are heavily overweight. Big sizes have to be provided for this consumer group. Europe is about to follow this tendency. Most European retailers offered only normal sizes according to the population's body mass. Sizes in the US are not standardized, while

[21]Cotton, Inc., Kim Kitchings, personal communication.
[22]Cotton Incorporated's Lifestyle Monitor™, 2002.

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in Europe nationally standardized sizes, based on a highly developed grading system, are now in the process of European harmonization.

The cut and fit of US apparel is considered to be inferior compared to European apparel. The newly developed 'body scan' technology (May-Plummly 2002) will certainly contribute to a better fitting of US apparel, if this can be offered at a moderate price.

5.5.5 Branding

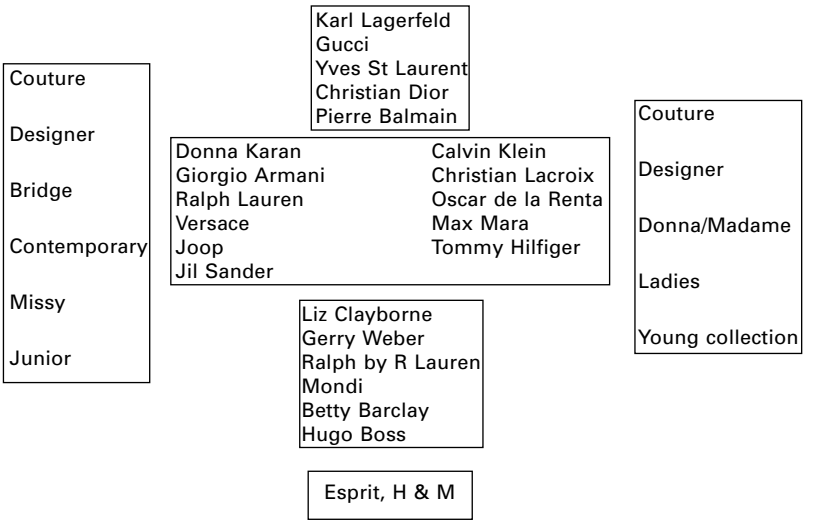
US apparel is based on national brands like Levi, Wrangler, etc., which made denim jeans available nationwide and was adapted by many apparel producers in mass merchandising. Introducing US brands in mass merchants, which are favored by young customers increased their margins and profits considerably. US consumers believe more in brands than in retailers (Cotton, Inc. 2003). This trend has been fostered by expanding brands from the moderate and higher segments towards mass merchandise. Private labels at department stores became more important, besides well-known national brands like Levi, Lee, etc. US consumers accept that practically the same private labels are offered in different channels at different qualities. An example may illustrate this: in the better segment, 'Hanes' intimates are made of combed yarn and include Lycra for a better fit (Elmore 2003). Visually the same brand, 'Hanes Her Way', based on carded yarn without stretch, is offered in the mass channel at a lower price. Such strategies prevent the development of quality aspects associated with brand names. As US apparel is penetrating European mass merchants, it is bringing this culture to Europe.

European brands are mainly located in the better design segments. European consumers expect higher quality from branded products and would complain about any inferior quality. An overview of European and American brands is given in Fig. 5.11.

Global labels for sportswear for young customers do not always guarantee the expected quality level. Tests on harmful substances in global labels indicate that quality tends to decrease under cost pressure. The few chains operating in the low and budget end established throughout Europe do not yet offer brands. Most consumers therefore associate brand names with expensive apparel, in which a great percentage of the higher price is actually based on costs for brand marketing (see also Section 5.7). Brand names are also known to stand for high quality as most of the companies are ISO certified. Specialty shops for sophisticated sports equipment offer private labels and extend their markets towards casual apparel, as younger customers are more interested in brands.[23] Due to this tendency, specialty stores for stylish apparel might lose some market share against specialty stores for sporty, casual apparel.

[23]Survey, ETH Zürich.

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5.11 A selection of designers and styles in the US and Europe.

Additional characteristics of labeling are defined by environmental labeling according to ISO requirements (see Chapter 1).

5.5.6 Services

Most US apparel retailers do not offer special lifestyle services such as suitability, coordination of clothing items or fitting services. Only some niche markets offer such services for well-off customers, mainly from the 'baby boomer' generation.

Especially in the rich-context cultures of Europe (see Section 5.3.2, Demographics), the purchasing environment is much more important than in the US. Apparel are presented very carefully even in moderate segments. Trained personnel provide services in style consulting, coordination of pieces and fitting. Communication becomes an important factor and contributes to higher purchases. Personal relationships between customers and personnel can be established, as many retailers operate small shops. Often retailers provide good services for fitting by well-trained personnel. In addition, open markets in southern countries offer various segments from low-end to better branded apparel, though without services.

5.5.7 Materials and care properties

Materials

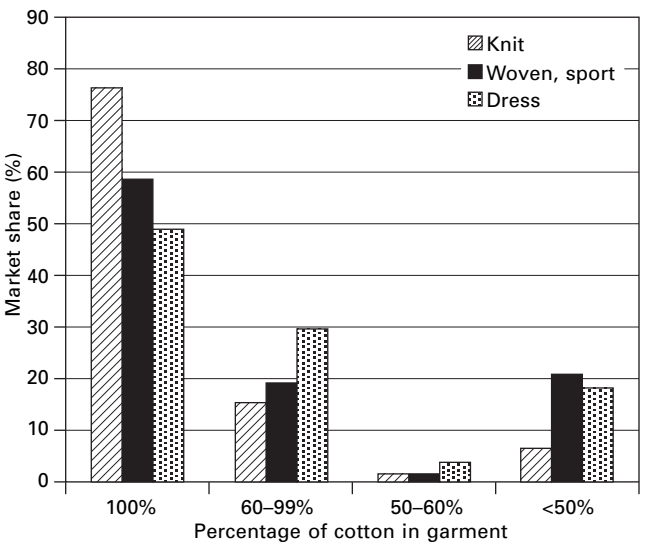
The most popular man-made fibers in US and European apparel are polyester, polyamide and acetate. In the European sector viscose has gained a small

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market share. The most common natural fiber in the US is cotton, while Europeans add some wool, linen and silk, mainly for the '50 plus' generation. The share of cotton in US apparel, particularly for leisure, is still very high (see Fig. 5.12). This trend goes along with the growing acceptance of casual dresses in the working environment. Americans wear more denim products than Europeans do. Nevertheless, formal dresses and suits for the younger generation are mainly made of man-made fibers, while the older generation and better-off consumers often require natural fibers or a blend. Man-made fibers increase wrinkle resistance, a function that is welcomed by business people. The emerging sector of functional materials for sportswear in high-end segments is mainly based on advanced man-made fibers. As comfort and care properties of such apparel are enhanced, this is a market opportunity for young people's casual apparel in the higher segment.

Care properties

Although associated with shortened lifetime expectancy, about one-third[24] of today's consumers worldwide require non-iron and wrinkle-resistant apparel. In the US, Brooks Brothers started to produce a wrinkle-less, soft carefree category for men in 1999 and one for women in 2002. In parallel, the brand 'Eterna' became well known in the EU, due to advanced product development, including yarn construction and finishing. The first fabrics



5.12 Cotton share of the US market (source: Cotton, Inc. 2003).

[24]ETH Zürich, own tests.

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were produced for men's shirts, followed later by blouses for women with the same properties.

The laundering properties go along with the choice of materials. Consumers prefer washing to dry cleaning. Surveys have shown that 70% of US and 80% of European apparel purchases are made by women. They still do most of the laundry, including ironing. As working women tend to reduce household work like ironing, they prefer apparel that is easy to care for, especially for the younger generations. Only the most formal dresses and suits are acknowledged to need dry-cleaning.

5.5.8 Shopping behavior

The European market was built on national retailers with only a few European chains. Established consumers are more likely to choose their national retailers. There are huge differences in shopping behavior between northern and southern customers in Europe, not only due to national cultures. However, cross-border shopping is becoming more and more attractive as people go on organized shopping tours (Städtereisen) to different cities. Retailers have to deal with consumers cross-shopping and have to adapt their marketing accordingly. Shopping behavior not only shows differences between nations, but has also been undergoing major changes, as Table 5.10 indicates.

A specific survey on shopping and buying behavior in the US is given in Table 5.11, indicating the move from shopping in chains towards mass merchants and the decrease in amounts of money spent on apparel.

Table 5.10 Apparel shopping attitudes

	Like/love shopping (%)		Average trips/year	
Country	1999	2001	1999	2001
Brazil	80	78	7	10
Colombia	76	78	6	8
Germany	73	66	16	12
Italy	76	73	11	21
United Kingdom	61	60	18	19
Hong Kong	32	27	16	16
Japan	69	70	8	11
Korea	50	35	15	14
Taiwan	69	78	11	14
India	–	92	–	6
United States	45	45	22	23
Total	63	64	13	14

Source: Global lifestyle monitor and cotton incorporated lifestyle monitor.

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Table 5.11 Development of shopping behavior in the US

	1994	2003
Women: love shopping	53%	57%
Men: love shopping	23%	24%
Planned shopping	53%	60%
Main shopping in chains	28%	19%
Main shopping in mass merchants	16%	20%
$ of $500 spent on clothes (men)	$202	$189
$ of $500 spent on clothes (women)	$278	$268
Women: denim garments owned	14	17
Men: denim garments owned	12	13

Source: Global lifestyle monitor and cotton incorporated lifestyle monitor.

5.6 Positioning of companies in the market

The macro-environment affects the company as well as its competitors. Competitors acting in an international environment might be in a better position on the common market. Although the American and the European areas belong to the industrialized countries, there are some distinguishing differences in their macro-environment. The most important differences are given by the political system, the structure of the industry and the culture in the two hemispheres. Additionally, demographic development has to be considered for long-term perspectives. There are differences in the structure of companies, in technology and in machinery, which contribute significantly to the present market situation. Consequently, trade in the two hemispheres develops differently as well.

Textile marketing must meet all the general requirements of marketing, including the analysis of the macro-environment and the micro-environment. It has to plan and control a marketing process, according to the company's vision, objectives and budget.

There are some general specialties in textile marketing based on individual textile product segments. Among textile products, apparel show the shortest life cycle (see Section 5.4), followed by home textiles and automotive. Technical textiles show a much longer life cycle as they are not subject to fashion. Generally, short cycles along with ever-changing fashion (products) make textiles such a demanding marketing issue. Apparel has to fulfill customers' needs for protection against weather, for wash-and-wear fabrics and for self-esteem (hedonism) all from the 'low end' up to 'haute couture'. Consequently, cost efficiency is a challenge, as prices for apparel show a tendency to erode, while prices for other goods like food increase all the time.[25]

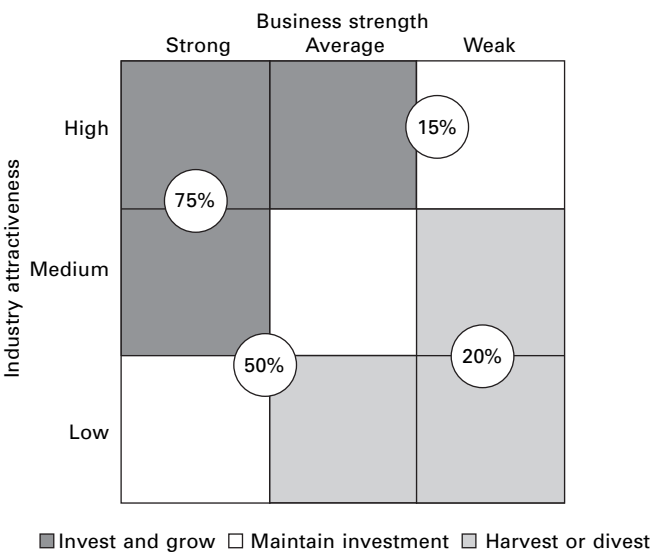
[25]Swiss statistics, 2005.

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The core policy of each company is its positioning in the market. It tells customers and employees who the company is and what values it stands for; it communicates the company's competence and credibility. It can also be described as its profile. It aims at occupying an appealing space in a consumer's mind in relation to the space occupied by competitors. In a highly competitive market such as in textiles and apparel, positioning comes first.

Retailers seek to provide the market with textiles and apparel that meet the consumers' preferences (see Section 5.5). The signals from the market are translated into the development of appropriate products (see Section 5.8) and in the effective marketing strategy. Marketing is part of the company's strategy and policy and must take a long-term vision, including capacity, technology and alliances.

A company needs to know its position in the competitive environment. A first step is to define market growth rates and market shares for individual product groups representing strategic business units (SBU) (see Section 5.7). Consequently a company has to analyze its business strength compared to the industry's attractiveness (see Fig. 5.13). Often the analysis of the company's own position does not exactly meet the target position. A strategy towards the aimed position has to be developed with SBU and implemented in product development, production (including technology and sourcing) and marketing strategies. Marketing strategies are the key driving forces in the supply chain, since they have to adapt consumer demand to product development, merchandising and sourcing.



5.13 Profile of strength and attractiveness of a company with percent market share.

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Marketing requires excellent monitoring and a proactive readiness for rapid changes in the development of unique products, based on technological advantage. Often companies stick to traditional selling and suddenly are faced with overproduction and declining domestic sales. They experience competitive pressure and react instead of moving to proactive marketing as shown in Fig. 5.14.

The strength of a textile marketer lies in his development strategies (creativity) and evaluation of multiple, analytical facts for flexible solutions. He must stand the flood of information from the consumer's side and convert it into streamlined strategies, thinking in different time frames. He must prove to have excellent social skills in cross-linking, communication and motivation. Thereby he sets goals and convinces his partners to follow these goals. He has a strong personality, he wants to succeed, and he has a high tolerance of frustration. By establishing a 'corporate identity' he includes all employees in his marketing strategy. Low hierarchical structures and participation allow appropriate communication and integration of marketing strategies (Cassil 2003).

Market studies and benchmarking provide the basis to concentrate on differences, not averages, and to compare with the best. Unique products and outstanding services represent the center. To build up a close relation with customers and suppliers as individuals is a demanding task.

5.6.1 Analysis of strengths and weaknesses

An analysis must include all competition factors of the micro- and macro-environment which are relevant for the company. The differences may become evident when investigating the company's strengths and weaknesses. The focus is on future developments, as addressed in Fig. 5.14, based on the company's potential with opportunities and risks. Fig. 5.15 gives a more general example of a SWOT analysis with strengths, weaknesses, opportunities and threats.

European and American companies have been investigated in two surveys. The European analysis was carried out in 2002 and the American survey took place in 2003. They will be discussed in the following.

Reactive	Proactive
• Competitive pressures	• Profit advantage
• Overproduction	• Unique products
• Declining domestic sales	• Technological advantage
• Excess capacity	• Exclusive information
• Saturated domestic market	• Managerial urge
• Proximity to customers/ports	• Tax benefits
• Unsolicited inquiries	• Economics of scale

5.14 Approaches to product and market development.

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Table 5.12 gives an example of a European manufacturing company (Seidensticker) and its strengths and weaknesses. A comparison of US companies covering the supply chain of textiles is given in Table 5.13.

Strengths	**Weaknesses**
Market dimension, market share	Product quality
Market growth	Internal know-how (employees)
Benchmarking, gap filling	Production: flexibility
Competition: competitors, prices	Flexibility, proactive strategies
Profit margin	Delivery time (obsolescence)
Geographic advantage/disadvantage	Knowledge of markets and customers
Economic situation, policy, legislation	Customer structure
Wages	Push–pull strategy in the market
Policy of financial services, currency	Supply chain management
Cash flow	Efficiency in sales
Opportunities	**Threats**
Product development, partnerships	Diversification
Product life cycle, seasonality	
New products	

5.15 Possible parameters for a SWOT analysis: strengths, weaknesses, opportunities and threats.

Table 5.12 Strengths and weaknesses of a European apparel manufacturer

Strengths	Weaknesses
The ability to produce great amounts of shirts and blouses in a short time in all segments is their unique selling proposition (USP) for cooperation with big distributors such as Aldi or Tschibo (Germany). Although production is international, the products are adapted to the local needs. Bielefeld is the European strategy center, whereas Hong Kong controls the local product adaptations for all overseas countries. The company's new marketing strategy has been implemented since January 2002. Before then, the company produced many brands, which competed with each other. The strength of each brand was not clear, because differentiations were limited. Economically the non-iron shirt is the most successful product, with ecological downsides: in Germany a shirt needs to be of cotton, which tends to crease so that ironing is necessary. Therefore the cotton is treated with liquid ammonia and synthetic resin.	The company's product range has been build up on the successes of their non-iron shirts of different materials since the late 1950s. Therefore the consumer's most important criteria for buying Seidensticker are (in decreasing order): 1. Ease of care 2. Quality 3. Long-lasting products These three criteria are almost impossible to harmonize. Therefore the number 1 consumer need is the one the company satisfies very successfully. Products, that are easy to care for have an impact on the fiber quality and therefore a shorter life span. There is a trade-off between the different criteria.

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Table 5.13 Threats, challenges and opportunities of US textile companies

	Threats	Challenges (2005)	Opportunities
Unifi	Commodity products	Eastern imports downstream selling	Performance versus aesthetic yarns
Burlington	Unknown future. Company has gone through many changes	Earlier strongly supported by Burlington Chamber of Commerce, actually merge with Cone Mills (purchased by Ross)	Product development for specific private brands
VF Corp.	Increasing competition, loss of loyal customers. Cooperation with Muslim countries like Indonesia and Egypt has become difficult for US companies	Mexico! Competition on price, labor, political issues, lead times and cultural issues like communication and working conditions. The position of China, the 'huge textile power house'. Tariffs and sanctions raised by the US government may replace the quotas in 2005	Wrangler in China, towards women, new brand acquisition and product categories, Wrangler Nascar (from horse to car)
Sara Lee	Operation of separate divisions, brands between vendors, pressure on price	The company's name is never mentioned in such a sense ('we are Sara Lee'). Consumer focus changes a lot: while apparel consumption (in value) has gone down by 3.4% in the last 3 years, restaurants increased by 18%. Internet information prior to shopping	Global markets, good brands, excellent organization, product development and merchandising
Cotton, Inc.	Competition of higher quality cotton products?	Position in WTO subsidies (US) versus globally oriented product development	Globally and fashion oriented strategy. Close to consumer

Unifi, formerly a traditional, technically oriented yarn producer, recently introduced an innovative marketing strategy. Burlington, a well-known weaving and finishing company, has outsourced many of its numerous plants to emerging economies. The globally operating VF corporation is faced with cultural disruption in the marketing strategy. Sara Lee is still not sufficiently recognized as an apparel producer, because of its well-known food brands. Cotton, Inc. represents the world's largest promotion organization for cotton products. The former domestically oriented promotion of cotton apparel has now changed towards a global promotion of cotton, including support of product development.

New opportunities can be found in marketing guidelines (Cassil 2003):

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- Trademarks
- Management with long-term orientation
- Good working relationship in distribution channels
- Lowest production costs
- Appropriate organization structure
- Well-known brand names
- Deserved reputation (quality, brands, services)
- Strong customer orientation
- Competent R&D department
- Intelligent forecasting of life cycles.

5.6.2 Company profile and consumer focus

One of the first priorities in a mature market is the company's profile and a carefully built-up consumer focus, to be clearly recognized by the consumer. If the consumer feels comfortable with the signals the company sends and the way he is received as a customer, he will consider this as a long-term partnership. Surveys from Europe and the US can illustrate ways by which a textile company may achieve this partership. Examples 5.1 and 5.2 present the European perspective of the survey, while Tables 5.14 and 5.15 address the US customer.

The chosen case studies in Europe and America indicate that American companies undergo stronger changes in the supply chain, particularly in their product range, than the investigated European retailers and wholesalers. Accordingly, they have to change their position. Company profiles often change as a result of a new consumer focus and new market segments. Changes in European suppliers are also frequent, but due to the structure with SME, changes in ownership are not as frequent. US retailers and wholesalers may be more exposed to takeovers because of the much larger volume.

Example 5.1 European company profiles

AKRIS is a family-run business, founded in 1922 to produce working cloth. After 1944 AKRIS grew up to a top quality ready-to-wear company and had first successes with license-production for high-couturiers – a business segment AKRIS kept by. It is the only successful Swiss company (100%) in the 'prêt-à-porter/haute couture' segment. AKRIS is officially accepted at the two official 'Prêt-à-Porter' shows in Paris since 1999. The turnover is around CHF 200 million/year, of which one third comes from each Europe, the Americas and Asia. Today 350 people work for AKRIS in St. Gallen.

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The **Seidensticker** Group is a family business, founded in 1919. The company is represented in over 30 countries and is not only leader in the European shirt business, but also internationally within the top five. It produces 21 million shirts annually, with 1000 employees worldwide, a team of 160 creative people launching 42 distribution programs nationally and internationally. Total turnover in 2000 was 301 million Euro (22 million from exports).

Migros Genossenschafts-Bund is the largest retailer in Switzerland. The total turnover of the company was 20.2 billion CHF in 2001; the turnover of the nonfood sector for 2001 was 484 million CHF. Eco is Migros' textile label and is a program for ecological and social production of clothes, home textiles and shoes. Together with a third party Migros controls all production steps worldwide, in order to ensure that their eco-guidelines are followed. The whole textile range is being ecologically optimized step-by-step. In 2001 more than half of the textile assortment was 'Eco-labeled'. Migros aimed to increase the share to two-thirds by end of 2002. Migros' turnover with the 'Eco-Label' was CHF 358 million (2001), an increase of 14% compared to the previous year before (www.migros.ch).

COOP is the second largest retailer in Switzerland. The turnover in 2001 was CHF 13.6 billion; the non-food sector represented CHF 4.6 billion out of which 16% was textiles, accessories and shoes. Coop 'Naturaline' is a label for textiles and cosmetic products, launched in 1993. Since 1995 cotton was cultivated biologically under the initiative of the yarn trade company Remei. All steps in the supply chain, from cotton to cloth, are ecologically optimized. Naturaline stands for well-being with respect to nature and is in line with clearly defined ecological guidelines. Even clothes produced in developing countries have to follow strict guidelines concerning social and ecological requests and fair trade principles. In 2001 the turnover of Naturaline textiles was over CHF 25 million, representing 35% of Coop's cotton-textile range. In 2002, a representative consumer survey in Switzerland showed that the Naturaline was 'well known as an ecological textile label' by 48% of the people interviewed (www.coop.ch).

JELMOLI was founded in 1833 by Jan-Pietro Jelmoli. In 1898 the glass palace of Zürich's main shopping mile was opened. In 1996 the company W. Fust took over Jelmoli. The principles: Jelmoli is competent and competitive in the areas of sports, accessories, beauty and household and therefore manages directly these segments.

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All the other areas are covered by 'Shop in Shop' partners (for example Christ, Fust, Coiffina, etc.). All these partners have a strong competence in their respective sectors and define the shops and products themselves. Jelmoli's goal is to be the retailer with the best service and advice in Switzerland. It is fashion-, trend- and lifestyle-oriented and considers itself a center for 'active consumers'. Focus is put on well-known brands, with a high-quality standard and highest value for money.

Example 5.2 Consumer focus of European companies

AKRIS considers consumer research as an important part of its business. It acquires data from its seven shops, getting weekly detailed sales information on the running collection. AKRIS decides on product directions to follow in order to please their consumers. AKRIS does not directly interrogate their consumers.

A new channel has been introduced with a 'personal shopper', a fashion adviser, helping customers to choose the right style and clothes. Many women in important positions have a personal shopper, in order to be adequately dressed at all times while saving time. In the US, this channel has grown quite big in large cities. This new sector will increase in the next years.

Seidensticker: Consumer research is done by means of different studies (Spiegel's Outfit 5 study, GfK and others; trend reports from fashion magazines or on the textile industry, own studies with Professor Hommerich). Seidensticker's consumer focus is influenced by adapting designer label trends (Dolce & Gabbana, Armani, Gucci, Prada) to the 'normal' consumer (benchmarking). Additional feedback on own products comes from retailers, who only order what they think is sellable without risk. Seidensticker is getting into new promising markets, e.g. industrial ready-made clothing.

Migros has a follower strategy: it imitates what others do best. Trends are primarily 'picked up' at European trend fairs. Additionally external fashion advice agencies give inputs on latest trends. The product managers occasionally visit trendshops and 'Avant-garde' boutiques of famous fashion houses (Armani, Versace, etc.) in the fashion metropolises of Paris, Florence, Düsseldorf and Amsterdam. Consumer research is done with IHA2 on a half-year basis. The 'Info-Line' (phone and e-mail) is for direct feedback from consumers.

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Consumers are not questioned regularly via internal panels; only if extra data are necessary, additional research is done. Migros defines its consumers as not only young persons, therefore not very 'trendy', not looking for prestige articles and 'labels'.

COOP: A lot of qualitative and quantitative market research is done. Each year Coop does an own consumer survey for the Coop Naturaline and their other ecological competence brands. Further information is gained from specific consumer requests. With category management a lot of consumer inputs come from the suppliers. Goals of category management are:

- Consumer oriented performance to increase the satisfaction of consumer needs
- Sustainable development as a competitive advantage
- Permanent differentiation from competitors
- Decreasing production and supply costs by managing an efficient process up to the point of sale
- Reviewing priorities of resources
- Increasing market share and yield
- Supporting cooperation processes with industrial partners on a 'win–win' basis.

Jelmoli: Direct consumer research is done by tracking sales volumes. Indirect research uses Jelmoli's 'Bonus Card', which was introduced some years ago. The card is the company's most important marketing instrument, because it registers buying patterns. Everything the consumer buys is traced, giving Jelmoli important consumer data.

5.7 Market segments and brands

Market segments are defined as low end, budget, moderate, better and design. However, today's patchwork identity of customers does not allow a fixed relation between income and choice of product segments. The same person may choose low end for many goods, budget for the majority of goods, better for some goods and even design on very rare occasions. Though such behavior might be difficult to understand, customers make up their mind about their perceived values of goods, such as price, quality and performance, including the purpose for buying. The general tendency goes towards price, even though European consumers may be somewhat more concerned about quality and good fitting of apparel than US consumers. Such differences may have their origin in the European system for sizes providing Europeans

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Table 5.14 US company profiles

Aspect	Unifi	Burlington	VF Corp.	Sara Lee	Cotton, Inc.
Competitor	Spectrum, McMichael, Sapona and Dillon	Cone mills, Milliken, Tex 5, Concell (Canada), Torey	Levi Strauss	FM?, Fruit of the Loom, private labels	Organic Trade Association
Company profile	Texturizing, dyeing, twisting, covering and beaming of multifilament PES (PBT butylenes), PA, spun yarns, elastomeric yarns	1960: 17 companies with great diversification operating in more than 100 plants. Today nylon, PES and some wool produced	Founded in 1899. In 1919 changed into Vanity Fair (VF) (including silk mills). In 1969 purchased HD lee and became VF Corporation. In 2003 purchased and marketed with Cone Mills	Food and clothing company. Large diversification purchasing companies with good labels	
Products	High performance textured polyester and nylon and dyed yarns for apparel (36%), automotive (17%), hosiery (21%), furniture (21%) and sewing yarns (2%)	Nano dry, nano touch (PES cotton like), nano care (cotton like), all mainly for men	Jeans wear, intimate apparel, knit wear, specialty apparel	Intimates in US, AS and EU	Cotton research, US lifestyle monitoring, product development for cost effective cotton apparel for global cotton mills

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Table 5.15 Consumer focus of US companies

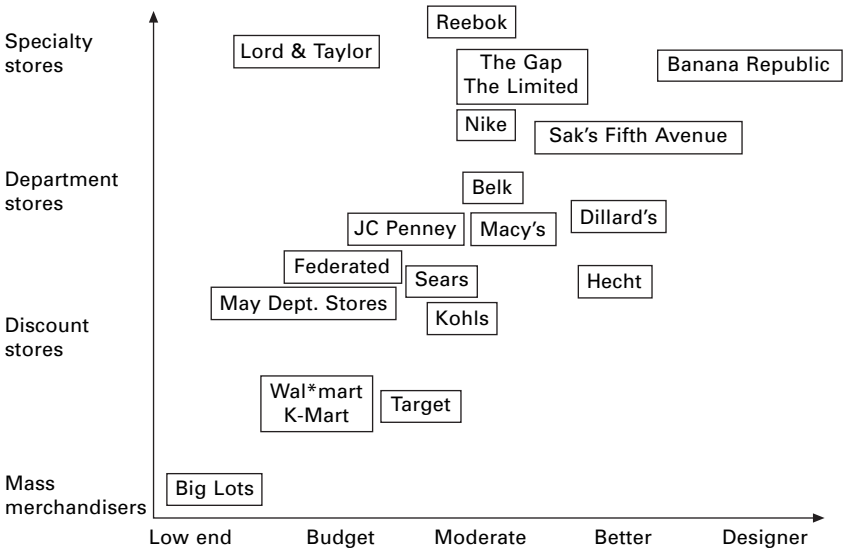
Company	Target consumers, consumer segments	Consumers' perceived value
Unifi	Warp knitters, circular knitters, and weavers (high)	High performance textured polyester and nylon and dyed yarns. Product information includes ply, denier, filament, type, fiber, luster, cross-section and core
Burlington	Men's and women's apparel manufacturer, military and uniform manufacturers	'Same' products are offered in different channels at different qualities and prices
VF Corp. (20X)	Wrangler: budget. Lee: moderately priced jeans wear for specialty Western stores, age 15–25. Children of farmers (rodeos, horse riding); also Hispanics	Girls are more fashion oriented in finishing, boys are more traditional. Costs of 20X $28–40, shirts $45
Sara Lee 'intimates'	Kohl's, Macy's, JC Penney, Sears, general private labels exclusively in department stores	Variety in cut (1), size (2), color (3), fibers and fabric type (4). Consumers should know quality is better in better distribution channels, but most do not care for it
Cotton, Inc.	Cotton growers, cotton mills, end consumers, all segments also high end addressed	Cut, fit, size (1), fibers, materials (2), care properties (2), younger generation: brands

with enhanced standards for fitting. Figure 5.16 shows the portfolio of US apparel producers in relation to the market segments. However, differentiation between the segments has become less and less clear.

5.7.1 Consumer segments

The definition of strategic business units (SBUs) requires focusing on target customers and mapping consumer segments. Demographics, value indicators and price are good criteria to describe consumer segments. The criteria mainly applied for demographics are age, net income, education, profession and family status (see also Section 5.3). In the area of value indicators countless criteria can be applied, such as aesthetics, fashion orientation (trendsetter, follower), attitude (understatement, traditional, etc.), expectation (quality, reliability, etc.), individual goals (consumption, safety, sensitivity) and shopping behavior (environment, atmosphere). The preferences for individual style represent another heterogeneous field. In the price–services relation, price elasticity may be a critical issue. Attributes of identifications are applied to come as close as possible to the customer needs. To analyze trends in the customer's values, his or her preferences are addressed (see Fig. 5.17).

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5.16 Portfolio of the US apparel market in relation to market segmentation and distribution channels.

Quality conscious
Fashion conscious
Care conscious
Price conscious
Environment conscious
Source: Baumwollinstitut Bremen

'The contemporary woman'	Fashion as lifestyle, independent, no age, practical, discrete, natural
'The contemporary lady'	Color, body-shaped, cultivated, spontaneous
'The instant queen'	Fashion, experimental, individual fashion mix
'Boy meets girl'	Young, discrete, masculine touch
'Yesterday's style meets tomorrow's talents'	Young, bad taste, new materials

Source: TMC Zürich

Pioneer consumer
Status-quo consumer
Narcissism consumer
Moral-plus consumer
Source: Trend office, Hamburg

Economic consumer
Egalitarian consumer
Materially conscious consumer
Brand fan
Trend-conscious consumer
Source: Brigitte

5.17 Different types of customer segments based on value setting.

The segmentation is as good as values are communicated, when data are being collected for surveys. The results depend on the methods applied in such social science studies. Large statistics (quantitative social science) work with defined answer categories, with which the questioned person has to identify himself or herself. Different cultures make it almost impossible

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to work with standardized categories. An easier way is to analyze what has been sold in structured market segments (see Table 5.16).

In the marketing environment, inspiration from product development, defined strategic business units and customer segments have to meet. Figure 5.18 shows that ideas from inspiration have to be transferred into stories and crosslinked to consumers' segments.

The marketing mix is a critical issue and requires permanent feedback of customer preferences. An appropriate combination of products, price, placement and promotion has to be achieved. The consumers' awareness of a company profile, including its reputation for quality and customer service, will influence the customer's decision to begin a long-term relationship.

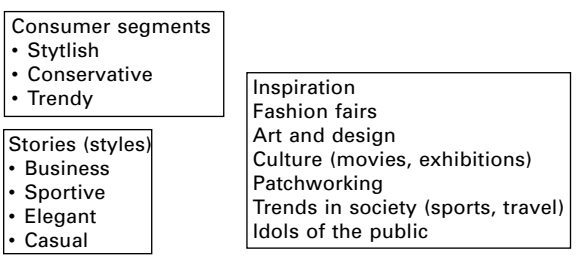
The reputation is strongly related to the product. There are two strategies for sales propositions:

- USP (Unique Selling Proposition) which differentiates by means of inherent properties of the product and production processes
- UAP (Unique Advertising Proposition) which differentiates indirectly by means of emotions, marketing properties such as brand, design, color, etc.

Then the company has to create a difference in value and communicate it to the consumer.

Table 5.16 Marketing study on apparel types in the USA (the allocation of the segment types is not clear cut)

Segment	Women	Men
Timeless, classic	34%	29%
Casual	25%	30%
Sportive	45%	45%
Elegant	17%	14%
Fashionable, trendy	16%	10%



5.18 Consistency between consumer segments, stories (styles) and inspiration.

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5.7.2 Life cycles and sales

While European consumers stick more or less to two seasons (spring/summer and fall/winter), the US market operates more based on customer-shared activities like 'Christmas shopping' or 'back to school' throughout the year. By doing so, American retailers get more in touch with people's lives, specifically addressing individual ages and lifestyles of customers. US consumers are conditioned to finding new products every time they go shopping. This driving factor for purchases has been created by the retailer's product life cycles or seasons, now up to eight to twelve a year.[26] Such a marketing strategy presents a high risk of wrong prediction of the consumer's behavior. Associated with the special events are sales, whereby articles are marked down dramatically (down to 50%) in order to increase consumption. Consequently consumers search for sales at any time of the year to get the lowest prices.

European sales for a long time were end-of-season's mark-downs. Consumers buying at the end of a season got a discount which was perceived as clearing of the stocks, because many articles were offered only in sizes not sold during the season. European markets seem to be more vulnerable to 'bad seasons', like summers with heavy rain keeping customers away from buying summer dresses. There might be sales for a specific article available in a limited number. Only very few articles can be purchased in different channels for (slightly) different prices. An overview on product life cycles and sales characteristics is given in Table 5.17. However, significant tendencies towards 'pre-seasonal discounts' and monthly life cycles can be observed in special markets for very young custumers in Europe, where entire shop offers are moved from one location to another.

5.7.3 Branding

Brands are essential for the image of a company, particularly for retailers and department stores. Life styles are to be considered and made consistent with fashion. As outlined in Example 5.3, European brands include a variety of criteria for selected consumer segments. Brands are developed with diversifications of promotion for individual cultures within Europe. Even environmental concerns such as those addressed by Migros and Coop are based, documented and communicated differently.

US brands are designed for identification of a rather homogeneous consumer segment, merely defined by economic criteria of the 'white' population. Black people are considered to follow white people in their consumer behavior. With the Hispanic population growing, a new shopping behavior is emerging

[26]Cotton, Inc., personal communication.

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Table 5.17 Comparison of life cycle and sales characteristics in the US and Europe

	US	Europe
Product is unique	6+ lines per year	2–4 life cycles
Distribution is limited	No product carried by all retailers	No product carried by all retailers, except for mail orders
High cost of fame	Consumer acceptance may mean 'loss leader'	Sales mainly end of season
Price	Price sensitive vs. price insensitive	Elastic: (added) value, fashion and fitting is more important
Forces of fashion	Single most important factor	Fashion and 'creation of a world', purchasing environment
Competitors and suppliers	Affect marketing success	Many small competitors working with common suppliers but individual fabrics
Teamwork	Partnerships are imperative	Partnerships are imperative
Power of the press	Consumer, trade, online, 'word of mouth'	Press is less relevant, except for economic data and societal issues
Technology	For processes and product	More prominent in Europe (machinery manufacturers)
Retailer's position	Pipeline to the consumer	Commitment of retailers and purchasing environment are important. Brands are less important. Labeling (ecology, fair trade) is a niche but growing market

Example 5.3 European brands and brand positioning

AKRIS has two different collections: AKRIS Prêt-à-Porter and AKRIS Punto (Designer Sportswear Collection). The AKRIS style is classical and timeless, quality is very important and creativity essential. Special AKRIS features are the 'Double-Face', requesting high art in manufacturing (e.g. 'blind seam' and the 'spot-design'). The spot can be found in every collection, sometimes barely visible, sometimes big, sometimes printed on the textile, sometimes knitted into the fabric, sometimes woven, in any variation.

The **Seidensticker** Group redefined their marketing strategy in January 2002, offering products in three price segments (Premium, Quality and Economy) in three different markets (category market, lifestyle market and special market). The category market is split in three product groups: shirts, blouses and nightwear. Jacques Britt is the premium brand, Seidensticker the quality and Redford the

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economy brand within the category market. The lifestyle market (casual products) is again covered by three different brands: Camel active (premium), Dornbusch (quality) and McKay (economy). Part of the special market is 'traditional folk wear' and outdoor clothing with the brand Alpenland, as well as Jobis in the ladies' garment industry (women's wear). Seidensticker holds licenses for Joop!, Bugatti, Burberry, Jean Chatel and Otto Kern.

Migros has 10 ethnic labels in the food and non-food sector. The non-food labels are 'eco', 'Bio-Baumwolle', 'Mioplant Natura' and 'Forest Stewardship Council'. The brand name 'eco' is self-explanatory, meaning that associations with ecological products are made instantly. Migros consumers want fashionable everyday and leisure wear at a good price–performance ratio. Migros' criterion with 'eco' clothes is that the price–performance ratio has to be right. The products have to be produced under the strict quality and ecological standards of Migros. Fashion trends need to be taken into account.

Coop sells branded articles as well as own brands (private labels) and competence brands. Coop has four competence brands: 'Naturaline' (label for textiles and cosmetic products), 'Oecoplan' (non-food), 'Naturaplan' (food) and 'Coopération/Max Havelaar' (label for fair trade with products from developing countries). Coop's Naturaline consists of 95 models of underwear for women, men, children and babies. In 2000 quality towels, jeans and women's blouses were launched. In 2001 men's shirts in a new quality, lingerie and new products for the baby assortment were introduced. Coop's Naturaline takes advantage of Coop's overall ecological focus. The Naturaline products are low price and not very stylish.

Coop's Naturaline concept supports:

- organic cultivation of cotton in India and other regions
- ecological optimization of the entire textile production process
- establishment of a traceable ecological production and supply chain/distribution
- consideration of extensive social requirements
- satisfaction of consumers' needs for textiles, produced with ecological and social awareness
- a wide and fashionable product range and clear and extensive product information.

Jelmoli declares itself as being the 'house of the brands'. The following brands can be found: Nike, Puma, Reebok, Asics, Adidas, Strellson, Joop!, Hugo Boss, Tom Tailor, Bugatti, Brax, Levi-Strauss, Orwell, Seidensticker, Miss Sixty, GAP, Academica, Kauf!, Mexx,

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Street One, Kookai, Sand, Bäumler, Betty Barclay, Bianca, Yves Saint Laurent, Mats Larsen, Origins, MAC, Estée Lauder, Sisley, Alessi, Mont Blanc, Fischbacher, Schlossberg, Riedel, Rosendahl, Villeroy & Boch, and Canali.

Jelmoli additionally has several partner companies, present as shop-in-shops in the building: Beach Mountain, Blumenhalle, Casa Colombo, Christ, Coiffina, Mövenpick Weinkeller, Directmedia, Estorel, Fust, Fogal, Hanro/Beldona, Holmes Place, Imholz, Koch Optik, Kiosk AG, Mats Larsen, Mister Minit, Minit one, Sunglass Shop, Terlinden, Teuscher, Varesino, and Walder.

Jelmoli is fashion, trend and lifestyle oriented. It had the first GAP and Schlossberg/Fischbacher stores as well as the first Canali shop-in-shop in Switzerland. Further, the only ORWELL shop and Nike Concept store in Switzerland are found at Jelmoli.

Table 5.18 Brands in US companies

	Marketing strategies	Brands
Unifi	Pull marketer – trade shows, press releases, editorial communication, co-branding	Sorbtek™, Augusta™, Reflexx™, Eclypse®, Inhibit™, Textra™, Novva™, Avada™, Mynx™, Sultra™, MicroVista™, Cielo™, Myriad™, Repreve® and A.M.Y.™
Burlington	Sales office in New York; define at the right time and to minimal costs	
VF Corp.	25 different marketing companies, individual strategies, numerous marketing channels	20X, Chic, Eastpak, Gitano, Healthtex, Jansport, Lily of France, Vanity Fair, Wrangler, North Face
	20X is a life style, advertised with country music, a sponsor of pba, Music of George Strait (Internet)	20X disdinguishes from Wrangler but is marketed in same company. Individual small business unit
Sara Lee 'intimates'	Brands are managed independently. Innovation of brands is achieved by means of specific meetings. Focused on consumer groups	Airé, Bali, Barely thee, Bereli, Cacharel, Champion, Chantal, Thomass Celebrità, Daisyfresh, DIM, Elbeo, Fila, Gossard, Hanes, Hanes Her Way, Hanes Sport, Just my size, Lovable, Nur Die, Playtex, Pretty Polly, Princesa, Unno, Wonderbra
Cotton, Inc.	Offices all over the world. Production: trend towards the Caribbean Basin countries (proximity to the US). Consumer shopping cycles increased (life cycles 6 weeks)	Cotton seal and cotton blend seals

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within the USA (see also demographics in Section 5.3). Branding can also be a result of a company's history as shown with Sara Lee intimates (Table 5.18). 'X20' by VF (Brooks 2003) and Unifi (Lewis 2003) represent newer trends with differentiations in branding.

The creation of global textile brands is a demanding task. Despite all the different cultures and languages, a company has to find a symbol, about which customers all over the world have beliefs and perceptions. The same name or the same meaning in another language is communicated. It has to address a similar image and position in each country or region. Though guided by the same strategic principles, the marketing mix must vary from country to country in order to achieve optimized identification (see also Section 5.5).

5.7.4 Sustainable marketing

The definition of sustainable marketing should reflect the viewpoint of the supply chain, which is somewhat different from the company's. Sustainable marketing strategies aim not only at maximizing the company's results, but also at a economically healthy business and a balance with environmental and social aspects. No other position in the value-added chain of textiles can drive the idea of sustainability as far as the marketing (Fassbind 2000). The ethical responsibility goes as far as to manufacture products with sustainable sourcing for a sustainable society, the life cycle of products from cradle to (factory) gate in accordance with ISO 14040 ff (Life Cycle Assessment). At the company level all operations have to be performed in a sustainable way according to the Eco Performance (ISO 14200 ff as outlined in Chapter 1). ISO 14000 (Czieslik 2001, Tobler 2000) should be combined with Social Accountability (SA 8000). Large textile companies have found their own definition of sustainable management (Pfister 2002, Vink 2003).

Table 5.19 analyzes management systems and environmental communication of US companies. Many US retailers do not maintain an environmental management system themselves but require specific efforts from their suppliers in foreign countries. The International Cotton Advisory Committee (ICAC), however, has launched a 'Better Cotton Initiative' (BCI) to improve on environmental impacts caused by cotton. Cotton, Inc. is very likely to follow such a strategy in future.

Marketing strategies have to cover all areas in product development, consumer focus and production of textiles and apparel as follows:

- Better use of inherent fiber properties
- Easy care properties
- Longer use phase
- Products recyclable
- Adapt production to consumer's need

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Table 5.19 Management systems and environmental communication of US companies

	Management system	Environmental communication
Unifi	ISO 9000 is perceived as the 'gold standard' of management systems. Finishing company is Öko-Tex certified for European market	Specifically addressed in company's entrance hall
VF Corp.	The VF quality control requires audits in all manufacturing companies (including packaging)	Auditors may ask employers individually about their working conditions (human rights, wages, working times, etc.)
Sara Lee 'intimates'	**Full packaging** (including spinning, weaving and finishing) is applied in sourcing, but Sara Lee owns information about **specifications**. Finance team for sourcing with Sara Lee, discussing product specifications with suppliers. Products tested with focus groups (consumers). Customers like J.C. Penney set standards (developed by own experts)	Decisions are taken in sourcing. A team of auditors visits companies in the supply chain and develops measures for environmental reasons
Cotton, Inc.		Not specifically addressed. Organic cotton not strongly promoted

- Domestic fibers
- Improved process control
- Less waste
- Low energy consumption
- Reduced auxiliary amount
- Reduction of transports.

The consumer generally is overextended to make decisions for environmental reasons, even if he or she wishes to take such responsibility. This makes marketing even more demanding, because the supply chain includes many companies, each of them offering a variety of processes and technologies that have to be optimized. This is the point where product development and sourcing have to focus on sustainability, by finding the optimized sequence of processes all over the value-added chain in order to produce the desired product properties (Meyer 2003). Such optimization can only be achieved by a very close cooperation with suppliers, allowing a certain degree of a push strategy. Other scenarios, mainly for big marketing companies, would be to introduce textile technology specialists in a product development team. Therefore partnerships with pre- and post-selling are a prerequisite for sustainable marketing strategies of a company.

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But the company itself also has a high responsibility for sustainability. The company's strategy has to focus on the '4 Ps'– product, price, placement and promotion – giving the company an orientation (Fassbind 2000, Kotler and Armstrong 2001). With publics (stakeholders) and politics added, this is referred to as '6 Ps'. Each company has its unique business portfolio. If this is analyzed and introduced thoroughly into the marketing strategies, the company can assert its position in the market. The business portfolio is based on factors of the company itself as well as on the micro- and macro-environment. Marketing strategies must have both a long-term and a short-term perspective. Especially the long-term strategies allow a sustainable orientation of the company. Whereas short-term perspectives of customer preferences are the heart of the micro-environment, long-term changes deal with changes in society.

5.8 Product development and merchandising

Textile articles are developed by apparel manufacturers or in retail/wholesale, depending on the distribution structure (see Section 5.9). Companies seeking unique fashion products have to be very skilled in developing styles (see Section 5.8.2). Inputs from fashion, technology, benchmarking with competitors and market research are merged into the design of new products in a pull strategy. New technologies in fabric production (push strategy) still may show a certain influence, but consumer preferences are the driving force for product development. Therefore market analysis and benchmarking are the tools for the creation of new products and new collections.

5.8.1 Strategies in product development

Strategies in product development must be in line with the company's positioning, its profile and its consumer focus. They have to integrate a number of fields (see Table 5.20) with practical measures.

The management of the supply chain of textiles and apparel does not follow the material flow. Whereas the processes from fiber to (gray) fabric can be considered as a linear flow (sourcing activities), the market-oriented part (from the finished fabric to the point of sale) is dominated by the market forces in retail and wholesale. These two main forces follow specific strategies in distribution (from the manufacturer's point of view) and sourcing (from the retailer's and wholesaler's point of view). In the end, it is the consumer who decides about purchasing a product or not. Retail and wholesale today have a most powerful influence on the supply chain with their sourcing strategies. Their business relation with apparel manufacturers is the gatekeeper for the material flows towards the customer. The nature of this relation is described in Section 5.9 on distribution.

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Table 5.20 Strategies in product development

Target	Allocate resources effectively (fitting company strategy)
Segmentation	View your market creatively (mapping strategy, opportunities)
Differentiation	Integrate content (determine function of unique product, context and infrastructure)
Marketing mix	Integrate offers, logistics and communication (not only 4 Ps)
Branding	Value indicator (avoiding commodities) determines price
Competition	Generate value for customer, not only for shareholder
Positioning	Customer orientation by means of credibility, trustworthiness, competence
Supply chain	Management of hub of network, process oriented
Integration	Company, customers and relationships (long-term relationship)
Services	Enhance product services

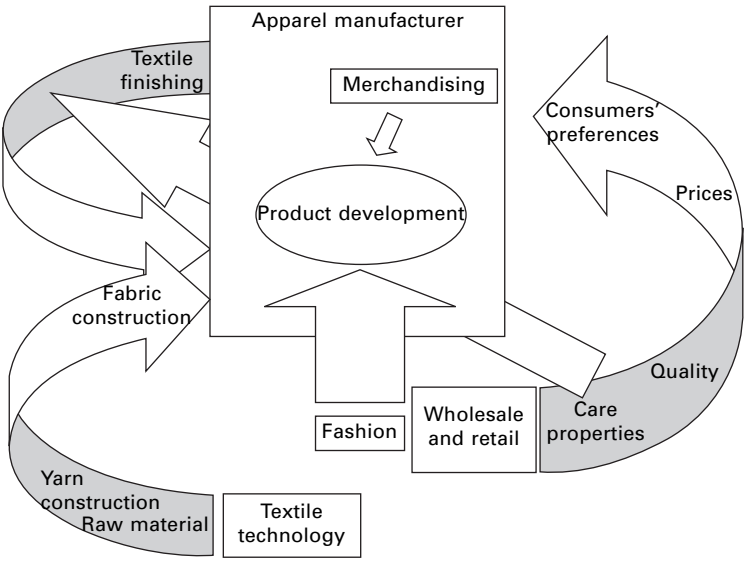
Big (US) apparel manufacturers cooperate differently in product development with mass production (national chains, department stores) and retailers (specialty stores), according to demand and volume of the purchase. In a global market opportunities for the establishment of (new) partnerships depend on size in an ever-changing environment. Small and medium-sized enterprises (SME) particularly in Europe may focus on specific consumer segments (see Section 5.7). Their products are developed exclusively for a limited number of specialty stores, often their own shops.

Most companies have established a cycle for product development, including marketing and merchandising (see Fig. 5.19). The example of Sara Lee shows a road map for product development in relation to the volume customers (retailers) are willing to order. Involved in this product development strategies are R & D, design departments in New York, technology input (innovations) and a strong marketing and merchandising force. The organization of a production processes includes several steps, such as a first selection of product lines, first collection (paper design), a set of specifications and quantities, and the presentation of the collection. The strategic management (innovation and sourcing) is strictly separated from the operational workflow.

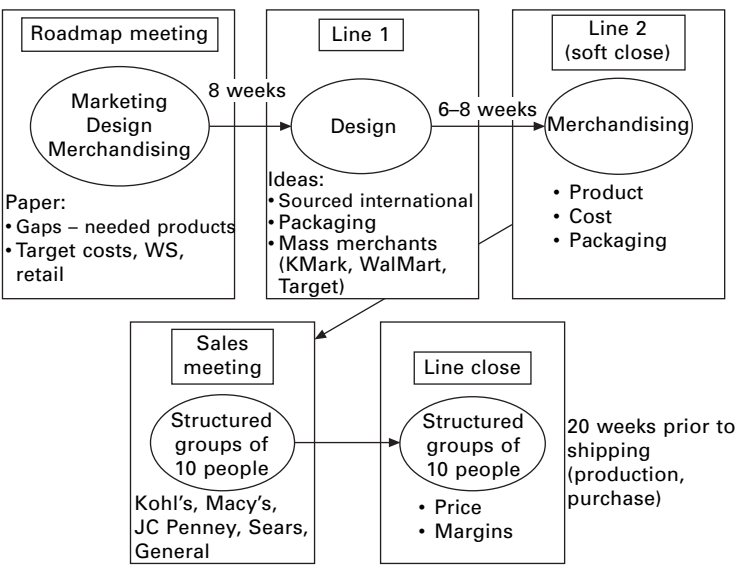
The organization of product development and merchandising is driven by scale and price. Figure 5.20 shows the strictly structured merchandising process of the US company Sara Lee Intimates, applied to be in time on the market, although the apparel is produced in Asia.

The ecologically driven sourcing of a company is quite different. Figure 5.21 shows the operational schedule of a German company, a SME specializing in ecological collections.[27] Product development is strongly

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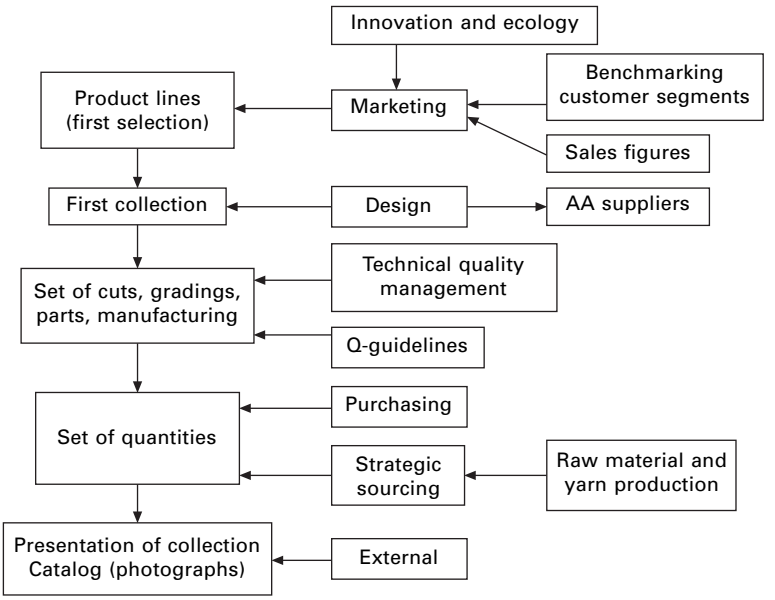
5.19 Typical product development cycle.



5.20 Product development and merchandising processes of Sara Lee Intimates.

related to innovations and requires adapted strategies, as the US survey in Table 5.21 reveals.

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5.21 Product development in a European company for an ecology-oriented consumer segment.

The process of integrating all aspects is a risky one: only 30% of all developed products become a success! As business is fully aware of this fact, product development is no longer a creative design process but an interaction with tough calculation of market merchandise risks. New fashions and styles create new market demand. In a highly competitive market an appealing style, low costs and reduced time to market are the main success factors. As a consequence some apparel companies divide their activities into design and manufacturing, the latter often being outsourced to reduce costs (see sourcing in Section 5.10).

5.8.2 Apparel styles, design and production

Mass-production fashion becomes a one-season issue, as ideas are less stylish but more extravagant to attract the consumer's attention. Consequently such products become more abundant with time and create opportunities for new fashions.

The reasons for consumers to look for apparel are multiple and mostly overlapping. Among being trendy, feeling good and sexy, setting a status

[27]Visit to Hess Naturtextilien in 2001.

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Table 5.21 Innovation and product development strategies of US companies

	Innovations	Strategy in product development
Unifi	19 yarns, one dyeing process, named yarns, taking fiber further solution, provider of ideas	Partnerships
Burlington	Fashion aspects	Develop products and colors for US (one basic, one neutral, one fashion) and EU (more colors); 80% for US, 20% for EU; new properties for men
VF Corp., X20	Cooperation with a contractor; brands, price, advertising, expansion; four life cycles per year, but still 1947 cuts on offer (longest product cycle in history)	Product development department also includes screening of trends; domestic niche market for the young Western generation; slightly changed styles
Sara Lee	R & D bring in new technologies (e.g. seamless) mostly before consumers take them up	System with five meetings in PD together with merchandising and customers
Cotton, Inc.	Smart textiles: information about the consumer's temperature, regulated emulsions from microfiber hosiery, stain repellency give textiles unique values	Promotion of cotton, mimicking of more expensive products. Also high-end products, carefree (wrinkleless) products, blending

symbol or expressing conformity with a particular group, the emotional need might be the driving force. US customers are particularly affected by trends and tend to dispose of apparel as soon as it is out of fashion. European customers may rely also on quality and feeling good, associated with status. Older consumers are willing to spend more money for an outfit (single piece), and to change their appearance with fashion accessories. Although denim is also very popular in Europe, it is less attractive for middle-class customers as they prefer stylish casual apparel. The younger generations in both the US and Europe seem to be more uniform as they take up younger styles and more active wear.

Styles

There are defined style categories in women's and men's apparel. For women, single garments are considered as 'dresses', while 'social apparel' includes

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apparel for special occasions, and 'suits', consisting of a combination of jacket and pants or a skirt, are worn for business purposes. The trend, however, is towards more casual dressing in business, although most business women still dress very formally. Among apparel for outdoor ('outerwear') and sporting ('sportswear') activities, the category 'active wear' becomes more important for a younger generation, encouraging designers to adopt this category, as active wear serves two subcategories: the fitness-oriented population and those who want to be fit. Other categories are 'lingerie' ('underwear' or 'intimates'), and accessories, i.e. scarves, hosiery, handbags and footwear.

Designers aim at creating ever new styles that outreach the mass of other designed apparel. Although new styles are invented every season, some of them have become classics like polo shirts, 'etui dresses' for women, blazers for men and women, and 'deux-pièces' of the 'Chanel' type. Styles are constantly being copied by means of cheap redesign for less well-off consumers (Valent 2003).

'Couture' is the most luxurious style, made to fit a client's individual measurements. Consequently costs range from $5000 to $50,000. 'Designer' offers a 'prêt à porter' collection of high priced ($1000–$5000), branded apparel, manufactured in mass production. The 'Contemporary' or 'Donna/Madame' style is for style-oriented customers with a lower budget ('budget' to 'better' in Fig. 5.16). In order to fill the gap between designer and contemporary, the 'Bridge' and 'Young Bridge' style was introduced by designers at lower prices. However, the segment of the Bridge style is the most affected in times of recession as it is purchased mainly by the upper middle class.

The 'Missy' or 'Ladies' style provides more conservative outfits in price ranges from 'budget' to 'moderate', while 'Junior' is designed for younger people and includes aspects of actual scenes (music, movies, events).

The terms for styles in the US are somewhat different from those in Europe. American styles are more differentiated by terms than the European ones, especially in the 'better' to 'budget' segments. In Europe the branded styles are strongly correlated with price and quality, while in the US a branded style is offered in different channels. In the European 'budget' to 'moderate' segment, apparel is often offered without a brand but by a well-known specialty store, whereby the name of the store stands for what a brand in the US would be.

The design process

Although product development is carried out in apparel manufacturing, the design process is highly influenced by requirements of the retailers (at point of sale, POS). This is where fashion, market demand (consumer needs

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and wants) and textile technology meet. Figure 5.22 gives an example of definitions of a company for babies'/children's apparel.

Designing fashion is a creative act demanding affinity to color, texture, style and appearance. The stylist chooses a selection of colors for combination, typically focusing more on warm colors for paler skin types or on cool colors for more tanned skin types. Color trends help to keep within a style. From all green colors, for example, an individual nuance is selected and addressed with a specific name like 'kiwi' or 'lemon' to contribute to the style. Color is the most powerful expression of fashion. Next to color comes the texture of a fabric, its properties being provided by the weaving and knitting design. The combination of a color with different textures creates different appearances in terms of the drape and hand of a fabric and contributes to a distinguishing style. But a style also brings along additional elements like the shape and silhouette of the apparel combined with details of tailoring.

This creative act is followed by more practical considerations like price calculations, sizing and fitting for selling. The designed apparel is placed in a lifestyle or contributes to a product line or collection. Comfort aspects like suitability for expected weather conditions (season) and allowing appropriate movement may be specified prior to the design process and have to be evaluated afterwards. The choice of a specific fiber or a fiber mixture contributing to the texture also sets the care properties and the lifetime duration of the apparel. Such quality aspects have to be evaluated carefully for the intended placement of the apparel, as they have to be compliant with the company's standards. Fashion aspects have to be adapted to quality aspects. Results from the US survey are presented in Table 5.22.

Production and sizes

Apparel production follows individual guidelines for manufacturing, including description of the workflow and quality specifications. The production of the required sizes determines to a great extent the success in the market.

The EU has a harmonized system for sizes not only in men's but also in women's, meaning that a German 40 corresponds to a French 38 and an

Essential attributes	**Desirable attributes**	**Useful extras**
Body-shaping fit	Easy to change	'Growing'
Moving fit	Easy care	Repairable
Insulation	Durable	Enforced parts
Temperature regulation	Reasonably priced	Kids' colors
Moisture transport	Cozy	Multifunctional
Protection against environment	Inspire senses	
Protection against allergies	Sun protection	
Freedom from toxic substances	Choice of colors	

5.22 Definitions of attributes for babies'/children's apparel development.

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Table 5.22 Fashion and quality aspects of US companies

	Fashion aspects	Quality aspects
Unifi	Partnerships	Product quality (lifetime duration) Technology, costs Customer relationships (products and services); Environmental aspects (in sourcing and towards the customer)
Burlington	Orientation in shops, fashion shows in New York, daily trend information	Slipping, pilling, color fastness, nano properties, shrinkage, stretch factors, breaking strength, etc.
VF Corp., Brand 20X	More hip, more sexy advertisement	Samples for washing tests Samples from the market are slightly altered and globally sourced as packages. In global sourcing terms of engagements are fixed by a compliance group
Sara Lee	Come into product development from New York	Data on testing and quality requirements are collected
Cotton, Inc.	Women's knits are increasingly important (appeal, comfort and care). Men's are less influenced	Large database Own machinery and testing, product development Products described with quality data for reproduction

Italian 42. Sizes for women in the US are less standardized. Generally sizes relate to customer styles, offering small sizes from 3 to 13 and from 34 to 42 in Junior and Young collections respectively. For Missy and Ladies, sizes range from 4 to 16 and from 36 to 44 respectively. The proportion of large women's sizes ranging from 14W to 32W is greater in the US than in Europe. Consequently only specialized stores offer size 42 plus in Europe. The 'Petites' (sizes 4 to 14) have an equivalent in parts of Europe called 'Kurzgrössen' (short size), whereby the size is divided by 2 (a 40 becoming a 20).

The following list gives an overview of production processes. It includes design activities, quality aspects, organization of production and sourcing.

- Description of model
 - Target group oriented
 - Function and value
 - Model design
- Development of cut and size
- Parameters for sewing
- List of parts
- Working plan

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- Pre-calculation
- Textile testing
 - Testing plan
 - Tests and parameters
- Quality guidelines
- Papers for control.

5.8.3 Sustainability in product development

In the 1990s European and American textile companies (Wentz 2003) started to integrate sustainability into product development (Braun 2000, Arretz 2002, Vink 2003, Traeris-Stark 2003). Two competing Swiss wholesalers have developed such activities and introduced sustainability standards, with different strengths and weaknesses (see Example 5.4).

Example 5.4 Strengths and weaknesses in sustainable product development

1. Migros

Strength: the 'Eco' label

Extraordinary in the industry is that Migros covers the whole textile assortment. By 2002, 70% of the whole assortment were being ecologically optimized (a step-by-step procedure to guarantee quality products). The price remained at the same level as it was before.

'Eco-Tex' controls the manufacturers regularly and also has worked out the auditing system for the production of ecological textiles. This was years before the label was introduced.

The following criteria are audited regularly:

1. Preparation of the information flux on pre-supplies (fiber origin and composition)
2. Safeguarding the waste water treatment by applying national law
3. Exclusion of chlorine-bleached products
4. Exclusion of pressure systems based on heavy benzene
5. Exclusion of all forbidden colors according to the Migros eco-criteria
6. Exclusion of PCP and PVC
7. Complete documentation throughout of all substances used
8. Reduction of all ecologically relevant harmful substances used in the production process
9. Creation of a socially accountable structure
10. Support of children.

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Strength: sustainable development

The four important ecological factors of the Migros eco-label are:

1. During the production steps of fibers – spinning, printing or coloring – the natural resources energy, air and water are preserved.
2. Substances that accumulate in the environment after production have to be harmless. For example: In order to protect the water, chlorine bleaching is abandoned. To protect the air, printing systems based on heavy benzene methods are prohibited. All manufacturing plants are connected to a sewage verification system.
3. Auxiliary materials and coloring matters that might lead to skin irritations or allergies are not allowed.
4. A 'Migros Code of Conduct' has to be signed. With the signature the manufacturer agrees to Migros' working conditions, medical and hygienic care criteria. Child labor is forbidden.

Weakness: problems with international labels

From a fashion industry and technological point of view, at least 65% of the textiles worldwide are produced ecologically, meaning that skin and environmental problems are minimal. Such statements lack careful verification. Ecological aspects need accurate definition, which Migros offers. The logistic boundary is obtaining all necessary information on the products.

Migros developed the 'Eco-tex' label instead of using the 'conventional' human-ecological concept for the following reasons:

1. The human-ecological sector takes into consideration only skin irritation criteria but no other ecologically relevant criteria.
2. Textile samples or samples of the completed goods are analyzed and either pass or fail the test.
3. Human-ecological analyses are not applicable on clothes produced in Asia, because as soon as the amounts are considerable, reliable analysis results are not possible.

Unfortunately Migros tests harmful substances only in the end product and not during production processes. In a future audit the label will be optimized. With the introduction of their own ECO–PRODUCTS label, Migros has the possibility to show their ecological efforts for the whole assortment.

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2. COOP

Strength: bio Re-supported projects

Bio Re supports projects in Maikaal (India), Meatu (Tanzania), and Antiochia (Turkey) for organic cultivation of cotton. Maikaal is an example of what such a project looks like: In 1992 a 6 ha area of arable land in the Maikaal region was used to cultivate cotton on a biological-dynamic trial basis. This project had an eminent success: nowadays Maikaal is the most important cotton production community worldwide. More then 1100 farmers cultivate arable land of 3000 ha and produce 3000 tonnes of raw cotton. For the farmers the cotton cultivation has a couple of advantages: the Maikaal spinning industry guarantees to buy the cotton and it pays a higher price for it. The cotton is not cultivated in monoculture and other useful plants are cultivated. The project is supported by the Bio Refoundation. The foundation finances community projects such as the construction of schools, irrigation plants and methane gas plants (COOP 2001b).

Strength: social requests for suppliers

- The farmers have a full-line forcing and get a higher price for organic cotton
- Voluntary work – no hard labor, no slavery, no exploiting labor camps
- No discrimination – equal rights regardless of race, sex, religion, political views
- Free contracting and debate on salary
- Secure existence salaries (minimum wages)
- Working hours not too long
- No child labor
- Humane working conditions.

Strength: sustainable development

The ecological competence brands are very important to Coop and have a high status in the company (COOP 2002). Coop's basic principles for environmental issues are:

1. The engagement with the ecological products creates a distinctive corporate image for Coop with the competence brands 'Naturaplan', 'Naturaline', 'Oecoplan' and 'Coopération/ Max Havelaar'.
2. They keep up with environmental law and try to anticipate future development.

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3. They define environmental goals, which are measurable and controllable.
4. They promote new technologies for ecologically compatible solutions.
5. They minimize litter and care about ecological disposal of packaging and products.
6. They promote reduction of energy consumption and support rail and water transport.
7. They demand that the partners' behavior is ecologically sound.
8. They foster awareness programs for employees on ecologically conscious behavior.
9. They strengthen initiatives with authorities and environmental organizations.
10. They communicate environmental aspects strikingly and effectively.
11. They recognize sustainable product development as an asset for the company.

Weakness: Coop Naturaline problems

Many fabrics are still made with conventionally grown cotton, where the following problems occur:

- Cultivation of cotton in monocultures, massive use of chemical herbicides and fertilizers, harmful consequences for nature and the health of the population
- Fitting-out the textile fibers with problematic and ecologically harmful chemicals, with health impacts
- Work under bad social conditions, no security, child labor
- Poor transparency for customers by ecological or conventional textile offer.

5.9 Distribution and distribution channels

The distribution process shows how the product is transferred from the manufacturer to the consumer. The appropriate product placement and positioning have to be achieved, along with an adequate advertising strategy. The term 'distribution' also refers to the position of the apparel manufacturer. The selection of an internal or an external channel is determined mainly by the size of the company, the vertical integration and the competition pattern. If a company chooses internal distribution it assumes the responsibility for the product characteristics and the control of distribution. Such companies work with well-defined consumer segments and quick placement on the market.

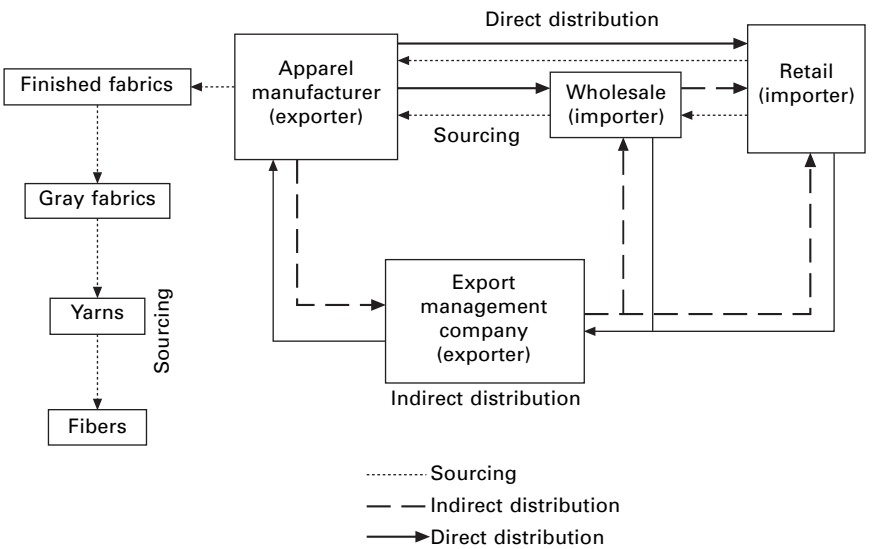
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Wholesalers have their merchandise stored centrally and distributed from there to the regional branches and shops. Others bring their goods to the non-food distribution center, from where the products go directly to the different points of sale. Strategies have to be adapted to the market development with the creation of new operational bases or distribution channels (see also Table 5.25 below).

The strategy can also be used for a desired market entry since it shortens the communication along the supply chain. Choosing external distribution requires a sound knowledge of the ever-changing market characteristics, specifically of the global competitors. Consequently also legal aspects become more important. High skills in communication and the development of (long-term) partnerships are required. In external distribution, intermediaries have the role of sales agents (contracting).

For a better understanding the external distribution process can also be analyzed from the viewpoint of the retailer and wholesaler as customers. The market differentiates between direct and indirect distribution (see Fig. 5.23). Distribution is shown here as export of manufactured apparel. The structure stands for all exports along the supply chain: raw material like fibers and crude oil, yarns, gray and finished fabrics as well as auxiliaries and accessories.

Direct distribution includes selling with and without contract as well as exporting by means of a retailer's service account. Such sales offices may be either company owned, a foreign subsidiary or a foreign independent sales



5.23 Distribution and sourcing channels between apparel manufacturer, wholesaler and retailer, with and without exporter.

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agent. The services provided include edition of markets, and monitoring of trends and styles. The offices often can provide access to specialty priced goods or new merchandise. Typically the associated fee is 7% of the sales price. Indirect sales require an export management company or an export trading company as an agent. The export management company may take a certain risk as it assumes the credit risks of the customer, whereas the US Export Trading Company is financed through the Export Trading Company Act's loan guarantee program (see Fig. 5.24). Driving forces for the choice of a distribution or purchasing/sourcing strategy in a global market are prices and lead times of products (see sourcing strategies, Section 5.10).

Of growing importance for product placement are the Internet and mail order, often used in addition to other channels of direct distribution. Even if sales through these channels represent only about 4% of total sales, consumers may search for information before shopping in other channels. The Internet serves to reinforce a buying decision. Particularly the younger generation are taking advantage of this facilities.

Retail operates with various channels that provide specific characteristics and are preferred for these typical aspects by groups of consumers, as shown in Table 5.23. Over decades the channels have been defined exclusively. Only in recent years, as consumers have started shopping in different channels, have these classifications become less distinctive. Mixing characteristics of different channels might attract additional customers and increase sales.

Table 5.24 gives information about the attractiveness of the different retail channels in the USA, chosen for men's and women's apparel. The consumer preferences give valuable information for product positioning. Figure 5.25 shows the structure of the Swiss retail market channels in the late 1990s.

Direct distribution
- Wholesaler buys direct without contract
- Distributor (long-term contract) buys product on commission or for resale
- Retailer buys direct from exporter by means of own service account, with prepaid maintenance
- Manufacturer buys raw materials from exporter

Indirect distribution: agents
- Export Management Company
 - works on commissions, salaries
 - handles exports for producers
 - arranges financing of shipments
 - assumes credit risks of consumers
- Export Trading Company
 - enforced by US Export Trading Company (ETC) Act
 - financing through ETC loan guarantee

5.24 Comparison of direct and indirect distribution: the agents of the foreign buying office may be resident or independent. They provide services like market edition, research in trend and style, buying options for new merchandise and market opportunities.

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Table 5.23 Retail distribution channels

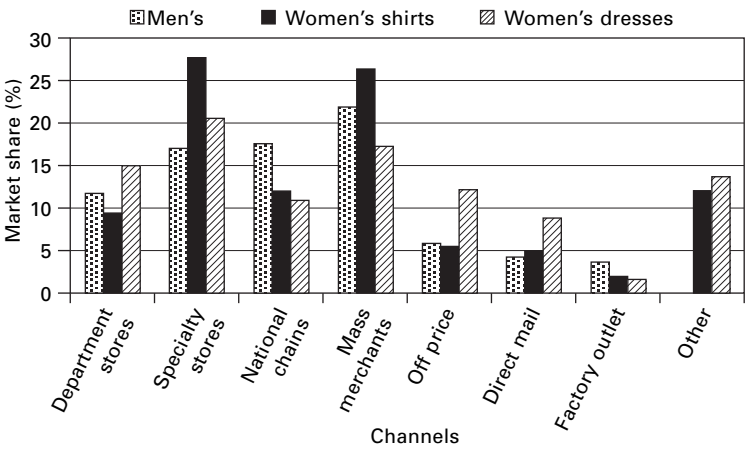
Department stores	Different merchandise in different departments of the same store US: limited number of personnel EU: depending on consumer segment Allow fast purchase of products of different needs Less choice in product range (apparel) EU: Galeries Lafayette, Harrods, Kaufhof, Manor US: J C Penney, Sears, Hecht, Belk
Specialty stores	Focused on fewer merchandise (apparel: men's, ladies', children's) Higher choice (styles, brands, colors) C & A, Gap, Victoria's Secret
Discounters	Mass merchants to low prices Kmart, Wal-Mart, Target
Low end	Small variety of merchants, extremely low prices Aldi, Lidl
Supermarkets	Large variety of food with some non-food departments Migros, Coop, Carrefour

Table 5.24 Market share (%) of channels in the USA

	1996	1997	1998
Specialty store	56.3	58.3	58.6
Department store	13	12.2	12.5
Low end	5.3	5	4.7
Mail order	10.9	10.4	10.5
Wholesale	11.3	10.7	10.2
Others	3.3	3.4	3.5
Turnover (million Swiss francs)	5984.8	6006.8	6200.1

The *placement* in distribution channels has to be chosen very carefully. Multiple strategies such as favored shop addresses, shop design and attractive Internet catalogs require high investment. Excellent services, especially at the point of sale, enable a personal relationship with customers. Promotion has to follow the trends: who and what is in or out, lifestyles of society, the role of women, patchwork identity of consumers, etc. Tables 5.25 and Example 5.5 give facts and details of US and European product placements and distribution channels.

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5.25 Textile turnover in Switzerland.

Table 5.25 Distribution channels of US textile companies

	Distribution channel
Unifi	Business office in Ireland to be closer to the European market
Burlington	Operating in Mexico and India, 10% international sales
VF Corp.	Kmart, Wal-Mart, Target
Sara Lee	60% of production go into Kmart, Wal-Mart (highest share) and Target, 40% to other retailers. Almost same brand in different retail channels (Hanes and Hanes Her Way)
Cotton, Inc.	Own channels, Internet, shows, etc.

Example 5.5 Sales outlet and direct distribution of a Swiss and a global designer.

AKRIS has eight boutiques worldwide in Paris, Boston, Monte Carlo, Düsseldorf, Frankfurt, Tokyo, Seoul and New York. In 1997 it opened the first shop-in-shop boutique, expanding to 35 shops worldwide. All stores are designed equally, with furniture by the architect Ferruccio Robbiani.

Logistics

The distribution is worldwide and direct. All pieces of the collection are packed in St Gallen and from there sent to all shops. The labels with all product references are also made in St Gallen and attached

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to each piece before sending. A piece made for America needs 3 days to reach its destination; for Asia 5 days. A small transport company, which only works for AKRIS, handles the shipments.

High polished magazines and catalogs

For a highly positioned brand like AKRIS it is a must to advertise in exclusive magazines. AKRIS decided to place advertisements on two to three pages in only a few magazines rather than on one page in many. Prices for advertisements in these magazines are very high. The star photographer Steven Klein shot photos for AKRIS. They are often in black and white and even more expensive.

ESPRIT shops are designed in line with the communicated lifestyle. The company's corporate image is visible in the ESPRIT architecture, the window layouts and the advertisements. For the best local presentation of the ESPRIT lifestyle, different shop concepts have been designed.

ESPRIT stores (company-owned stores)

Twenty-two stores and two factory outlets are owned by ESPRIT in Switzerland. All these stores have been designed by star architects like Ettore Sottsass, Antonio Citterio and Aldo Cibic. There are also seven classical franchise stores in Switzerland which cannot be distinguished from the ESPRIT stores by the consumers.

Shop-in-Shop

This concept was created to give ESPRIT partners the possibility to sell young fashion to show the ESPRIT assortment in the ESPRIT look, giving ESPRIT 'corner identity'. The concept was created in 1997. It also allows small shops the possibility of showing ESPRIT in the typical look.

Catalogs

In 1980 the first catalog was launched, breaking stodgy mail-order design conventions. It got record response rates and made ESPRIT a household name and without advertising. In the 1980s ESPRIT was the first big company to use recycled paper and cardboard for its catalogs. The printing was done with an ink based on soy. In 1998 ESPRIT celebrated its 30th birthday, for which the catalog was relaunched.

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E-Commerce

In 1998 ESPRIT went online. In the beginning the homepage was a new channel to present products and give information. Today e-shopping is mainly used by consumers in America. The turnover with e-commerce is still low. Nevertheless it is important for any company to be online as a presentation and communication platform for its customers. E-commerce will never become important for ESPRIT moneywise, since buying clothes is a very emotional action, which cannot be transmitted online. Instead by going to a shop, the consumer has the possibility to touch the clothes and be advised by a salesperson. E-shopping is only attractive for consumers if they know exactly what they want to buy.

5.10 Sourcing

From a manufacturer's perspective raw materials for apparel are sourced from spinners, weavers and finishers, who consider themselves as producers. The term 'sourcing' emerged with the shift of product development towards apparel manufacturer and the market. The pull strategy weakened the position of the suppliers in the value-added chain, who developed products in earlier years and pushed their products to the market.

5.10.1 Domestic production

After World War II textile and apparel production became more and more global, involving also countries in Asia, South America and Africa. These countries all went through different stages from manufacturing of simple goods for the domestic market (embryonic) up to enforced exports based on a well-developed industry with a good and cheap labor force and considerable foreign investments (see Sections 5.2 and 5.4).

United States

Apparel production moved to the southern US when in the 1960s wages became a critical cost factor. The next step in order to cut costs was to allocate labor-intensive tasks to countries with lower wages (to the so-called 'sweat shops'). Today 95% of all apparel consumed in the US is produced outside the US, mainly in South Korea, Thailand, the Philippines, Vietnam, Malaysia and some countries in Central America. However, 30% of the

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fabrics for apparel are produced in the US.[28] Production for military clothing will remain domestic, due to the legislation.

The US experienced hardly any competition from imports until the early 1960s. The production of large quantities of conventional textiles and apparel was assigned to the domestic market. The lack of domestic technology development prevented to a certain extent the development of innovative and competitive textiles and apparel. This allowed market penetration from developing countries by increasing imports of mass merchandise, produced at much lower cost. As the US customer is primarily cost oriented, such cheap goods were well received. Although the US textile industry partly lived off exports to developing countries, it pushed the US government to take measures against such 'market disruptions'. Along with the Multi Fiber Agreements (MFA) from 1974 to 1993, national attempts at protecting the US market were launched, though with limited results (see Section 5.4.3). Retailers did not want to support these politically motivated measures as they wished to have all possible opportunities for cheap global sourcing. In 1990 apparel manufacturers moved also to global sourcing, aiming for lower prices, which they could realize by producing in developing countries. A shift from apparel production to home textiles and furniture took place over a period of several decades in the US. Furthermore, man-made fiber producers, operating worldwide as monopolists, achieved considerable growth. They developed large R&D departments and provided materials for the growing market in apparel and home textiles as well as for technical and automotive textiles.

As US consumers identify more closely with brands, which are offered in different qualities, retailers seek out sites with the lowest production costs for the lower-quality products of their brands. Unless retailers and consumers change their attitudes to quality aspects, the trend in outsourcing of textile production for apparel will increase.

Europe

In Europe, where the EU has grown steadily since its foundation after World War II, textiles and apparel did not develop the same way as in the US, due to the traditional patterns of national markets. Textile and apparel companies are mainly family owned and much smaller than in the US, as they produce mainly for the European market. The European countries have always maintained large trade activities with each other because of their proximity. European textile machinery was export oriented towards the US in a beneficial partnership. When GATT was established the EU promoted

[28]Presentation to industry panel, Greensboro, NC, 8 September 2003.

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stronger support and a fair trade for equal rights with the developing countries. The UK, Germany, Italy and Switzerland were always the driving forces in the development of innovative, specialized, high-quality fabrics designed for fashion shows in Paris, Florence, London and Düsseldorf. Nations like Germany, Italy and Switzerland also invested in the development of technology for technical textiles, linking machinery and fabric closely together. As wages in these countries are very high, companies have had to maximize manufacturing automation in the last two decades in order to remain competitive, even in the high-quality sector. France and later the UK had lost their competitiveness in the textiles business due to the fact that they lost track of textile technology development and companies failed to increase their productivity. Labor-intensive apparel production shifted towards the southern and eastern countries in Europe, and the Maghreb countries of North Africa (Algeria, Tunisia and Morocco).

In spite of the growing global competition, a considerable number of European textile companies remained competitive through their innovation and fashionable design. They reduced their costs by restructuring, and they increased cross-linkage of product development and marketing with the supply chain management. The Central Europe based textile machinery industry was able to retain its reputation in the international market in spite of fluctuations in European demand up to the 1970s.

An increasing number of Asian students began to follow textile educational programs at universities in Europe and the USA. Many of them transfer their knowledge to developing countries. The slight decline in demand between 1970 and 1985 was not considered a consequence of this knowledge transfer. Suddenly Central European production started to decline dramatically in the 1990s, when a million jobs were lost. In the 1990s outsourcing towards East European countries became important (see Section 5.10.2).

Before the beginning of the twenty-first century imports of apparel from Asian countries for European mass merchandise increased dramatically. Mass production in Europe was no longer profitable. In 2003 the European textile industry (EU 15) still consisted of 177,000 companies, mainly SME, that generated a turnover of 200 billion euros with 2 million employees. With the enlargement to EU 25 in 2004 another 500,000 employees in the textile sector were added[29] (EURATEX 2004). Consequently the trend in European production today goes towards specialized, high-quality apparel made in the EU. As quality awareness of Asia's growing upper class grows, such apparel with good design and famous brands has a bright future in these markets. However, the new members of the EU with a high potential of relatively cheap textile workers so far lack the access to top-quality fashion and to

[29]http://www.euratex.org/content/environment.html

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sound, environmentally friendly textile technology. We may expect a fast catch-up, because the legal requirements are essential for market access. Similar developments are known from regions in Asia entering the European market (Tobler 2006).

The EU is committed to a high level of environmental protection. In 1996 the process was launched with the IPPC directive (Integrated Pollution Prevention and Control) and since 2002 it has been implemented in all member states with sector-specific documents of BAT[30] (best available technique) (see also Chapter 1). An EU report[31] admits that most SMEs are not able to guarantee that all legal requirements are fully met as they may not have the appropriate environmental knowledge. A study of KOF[32] gives evidence that environmental legislation is a barrier for innovation: in companies with less than 50 employees in the eighth position after other barriers, in companies with 50–499 employees in the fifth rank. Environmental legislation in many European countries requires large investments from textile companies and has forced many of them to close down (BAFU 2005).

The new members of the EU, often former outsourcing countries (e.g. Lithuania, Poland, Czech Republic, Hungary and Romania – see COST Action 628[33]), have increased their research activities in environmental technologies. The most prominent environmental problems concern high volumes of contaminated textile effluents.

The Swiss textile industry also mainly consists of family-owned SMEs with a long business tradition. Its main trading partners have always been the EU nations. As in their EU neighbor countries, many textile companies face an economically critical situation, mainly caused by the cheap textile imports. However, Swiss wholesalers and retailers profit from low-price apparel from developing countries for European markets.

The global perspective

Europe and later the USA developed global market activities centuries ago. Due to the low purchasing power in developing countries, such activities were restricted to countries with well-developed economies and to the upper classes. Now that industrialization is growing rapidly in emerging countries, they are going through the very stages that Europe and America went through earlier (see Section 5.2). First they develop domestic and later

[30]http://eippcb.jrc.es

[31]Kommission der Europäischen Gemeinschaften: Mitteilung der Kommission an den rat, das Europäische Parlament, den Europäischen Wirtschafts- und Sozialausschuss und den Ausschuss der Region, Brussels 29 October 2003.

[32]Spyros Avanitis, KOF, Hemmnisse bei Innovationsaktivitäten.

[33]www.texma.org /COST.

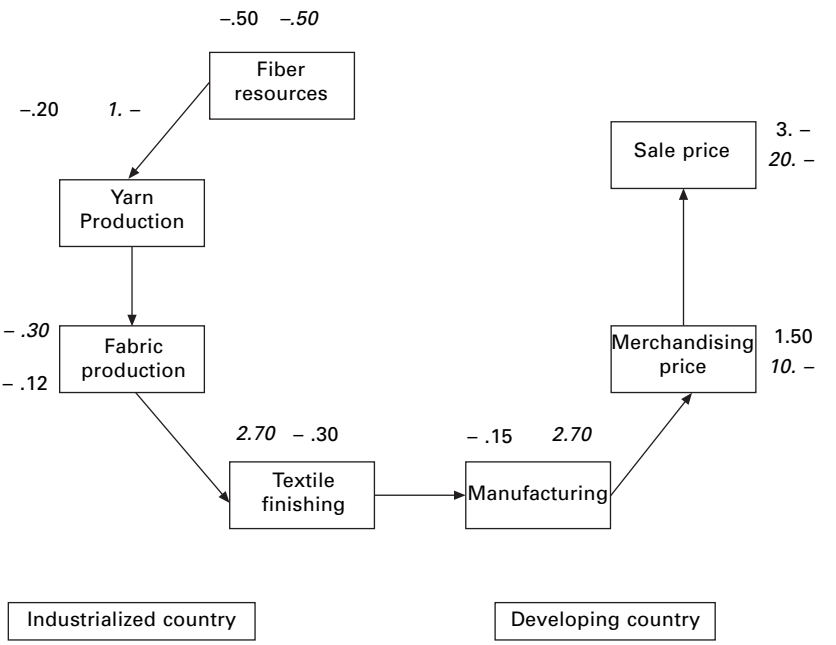
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global markets, following the theory of Porter *et al*. (1991). As a consequence of the goals of sustainability, the emerging economies should be given the same opportunities that earlier generations of the industrialized economies enjoyed. (The EU has agreements for zero quotas with many countries, whereas the US still works with quotas increasing the prices for imported goods.) However, we must not forget that sustainability also demands the same opportunities for future generations.

5.10.2 Outsourcing

Enlarged transportation possibilities facilitated outsourcing of textile production to remote countries. As the textile and apparel industry is one of the first industries to emerge in developing countries, opportunities for global sources are widely spread. The main driving force is cost reduction but this is associated with longer lead times. Companies may also choose outsourcing for a greater product variety for individual markets.

There is a variety of decisions a company has to make for its sourcing strategies: political stability and good means of transportation (roads, access to ports) might be only the first criteria on which to base a decision to source in a particular country. The choice of a country determines tariffs (additional



5.26 Value added for a T-shirt in euros for developing and industrialized countries.

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costs for imports, specified for individual countries) and quotas (limited imports until 2005) as well as transportation and other costs. The USA and the EU differ in their policy towards quotas and in the areas for sourcing, partly due to their geography and trade agreements (see Section 5.4).

Production costs for commodities are considerably lower in emerging countries than in industrialized countries (see Fig. 5.26). Besides wages and energy, costs also include maintenance of equipment, depreciation, rental costs, and insurance. Other important factors are the availability of technology and access to credit facilities, the provision of facilities in the sourcing location, and the production capacities.

Considerable investments have to be made in logistics, raw material supply, local infrastructure development and waste management (effluent treatment and solid waste treatment). Constant inspection and control by the client's intermediary agents is necessary in order to maintain quality and lead time. The quality inspection in the sourcing location is usually more expensive than at home. Additional costs have to be integrated for licensing and transportation such as shipment, fees and tariffs.

The labor force of the chosen region has to be evaluated not only in terms of costs (wages) but also in terms of the required skills, the reliability of employees, which may be based on the cultural context, and the commitment towards the client. A company may also have to face practices that are seen to violate human rights, such as child labor, poor working conditions, minimum wages, long working hours, safety and discrimination. The outsourcing company has to prove agreements with social standards.

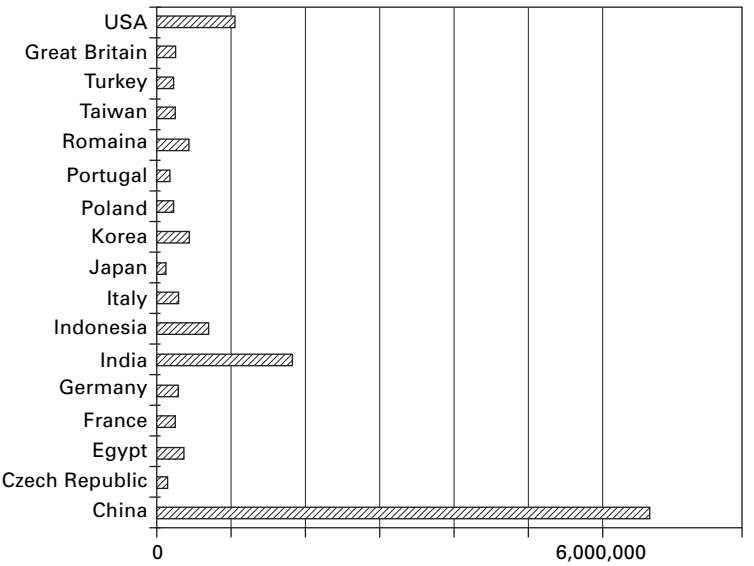
Most developing countries have no or only minor regulations for environmental issues. Consequently a booming industry can cause severe impacts for the country in the near future. The EU commits its companies to investments in cleaner technology by establishing national centers for environmental expertise. The US government does not support such issues, leaving it to the outsourcing company to establish standards for environmental management in the sourcing location. On the one hand, implementation of environmental standards may be costly; on the other hand, the image of a company contributing to pollution might have consequences for the customer's choice, especially in Europe.

The work force of the textile sector in Asia was concentrated some years ago in China and India (see Fig. 5.27). With the rising wages in those countries, some companies have shifted to countries with even lower wages but perhaps higher risks, considering quality and delivery time, politics, environmental damage and human rights (see Fig. 5.28).

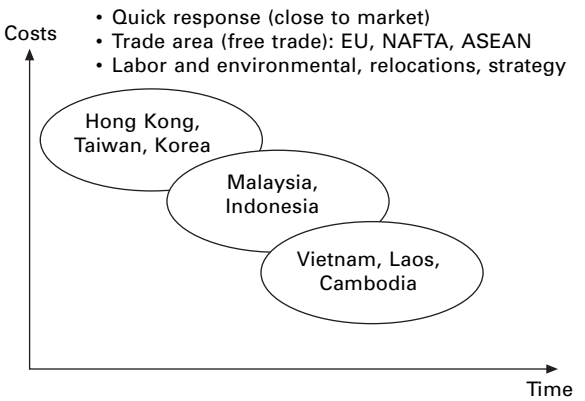
Sourcing options

The most critical issues for sourcing are quality standards and quality control.

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5.27 Employees in textiles and apparel (source: ILO 1996).



5.28 Dislocation waves caused by labor costs.

Today an apparel company has the following options for sourcing, sorted by decreasing degree of quality control:

- Domestic fabric and apparel production in an owned plant (integrated)
- Domestic fabric production with a domestic contractor
- Domestic fabric production or foreign fabric production, but cut domestically (tariffs only on 'added value')
- Foreign fabric, offshore production, owned facility
- Domestic fabric, foreign contractor
- Foreign fabric, foreign contractor.

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Time to market is determined by the time for transportation as well as the production time of the manufacturing company. A company may choose among the different sourcing options listed above.

The traditional company defines the single parts for sourcing. For the logistics three fields are important:

1. The fabrics
2. The accessories (like buttons, zips, threads, lining)
3. The turn-outs (like tissue paper, cardboard (boxes), bags).

Seidensticker, an EU company, searches for weavers that can manufacture the fabric after the criteria of the company. A kind of cooperation is established with the weavers and they build a cluster. The main problem is the delivery time. For fabrics this period is very long; it takes two to three months from the order to the delivery. For accessories the delivery time is much shorter. In this sector flexibility is requested when the demand changes, like a different shirt-collar or button color. For this reason, relationship management with the key supplier is fundamental. Every accessory and part has to be registered.

Particularly in fashionable apparel, short lead times are essential, as life cycles are very short in US apparel production and are also becoming shorter

Table 5.26 Sourcing strategies of US textile companies

	Sourcing strategies
Unifi	Production in US, Colombia, Ireland, England and Brazil (M H). Unifi Asia Ltd in Hong Kong for securing business through Asian contact. Joint ventures with Thailand and Israel
Burlington	Own and self-operated facilities in the US (with plants in South Carolina and Virginia) and Mexico (denim) (mainly for military), including textile specifications are exchanged. Partner Mills in Asia (China and Taiwan). A company, Nordstrom, is responsible for production with partners in Asia and the Caribbean Basin (cut and sew)
VF Corp.	The lack of flexibility of US mills: some owned and operated domestic mills (Red Cap in Nashville), specifically for uniform production and blank denim (for private labels). Cooperation with a contractor whereby VF Corp. only provides accessories. The trend in global sourcing is towards a full packaging
Sara Lee	Full packaging (including spinning, weaving and finishing) is applied in sourcing, but Sara Lee owns information about specifications. Finance team for sourcing with Sara Lee, discussing product specifications with suppliers. Products tested with focus groups (consumers). Customers like JC Penney set standards (developed by own experts)
Cotton, Inc.	Cotton first. If required properties cannot be achieved, blending with other materials

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in EU apparel production. The tendency in apparel production goes towards contracting full packages. This turns the manufacturing company into a merchandising company (see Table 5.26). However, product development is driven mainly by the US home-based companies.

Two cases may illustrate how outsourcing takes place over the years: the Swiss case and the Bangladesh sourcing example.

The Swiss/European case

The Swiss case is shown in Fig. 5.29 from the standpoint of a European company that first develops cooperation individually with its neighboring countries and later moves to Asian countries.

Case study: The Bangladesh sourcing example

Bangladesh developed facilities of an incredible size, even by US standards. Apparel manufacturing plants of the size of 10 US plants have been established and new airports with high international standards have been constructed for global trade. Monthly wages for an employee are $50, for a plant manager $500, allowing the companies to provide their employees with a reasonable living. Apparel production is raising the economy of the nation.

In August 2002 as quotas were suddenly about to be achieved, a US company's merchandise was held in Customs. The company, Vanity Fair, sent four freight airplanes to Bangladesh in order to get their sourced apparel out of the country. Two of them returned, full of sourced merchandise. The

Manufacturing	
1960s	Sursee (in Lucerne county)
1970s	County of Lucerne
1972	Romont (western Switzerland) until 1993
	Chiasso (southern Switzerland) until 1996
1983	Hungary (280 employees)
1990	Portugal (320 employees)
2003	Production in India and China

Finishing	
1990	99% in Switzerland
1994	9% in Germany
	1% in Hungary
1995	20% in Germany
	2% in Portugal
	1% in Hungary
1996	18% in Germany
	5% in Portugal
	1% in Hungary
1997	16% in Hungary
2000	China

Sourcing	
Until 1970	100% ion Switzerland
From 1997	15% in Switzerland
	45% in EU
	40% in eastern Europe

New orientation
1994 Joint venture with India (knitwear)
1996 Joint venture with Portugal (for US market)
1997 Joint venture with Joop: synthetic fibers (small segment, high prices)

5.29 Portrait of the outsourcing history of a Swiss apparel manufacturer.

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rest of the merchandise had to be left in the country. US competitors like Wal-Mart and JC Penney made the same effort to race their products home. Due to the urgent needs for the US markets, the WTO allowed Bangladesh to use their export quota to the USA of 2003 at an exchange rate of 3 to 1.

5.10.3 Sustainable sourcing

Sustainable sourcing includes all economic decisions and adds standards for environmental protection as well as social aspects such as human rights and local development of the workforce's communities. It is only fair to set a global standard for environmental protection and to improve social aspects locally. Any other strategy must accept the claim of unfair competition.

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